Part I:

MEASURE ANALYSIS and LIFE-CYCLE COST

2005 California Building Energy Efficiency Standards

CALIFORNIA ENERGY COMMISSION

Contract Number 400-00-061

P400-02-011
April 11, 2002

Gray Davis, Governor

Prepared by Eley Associates (Charles Eley)
San Francisco
Contract Number 400-00-061
April 11, 2002

Subcontractors: Berkeley Solar Group
Enercomp
Davis Energy Group
Taylor Engineering

Bryan Alcorn, Commission Contract Manager
Bill Pennington, Commission Project Manager

Table of Contents

Introduction ... 1
Summary of Measures ... 1
Acknowledgements ... 2

Nonresidential Lighting Power Density ... 3
Overview ... 3
Methodology ... 4
Results ... 4
Recommendations ... 7
Bibliography and Other Research ... 11

Demand Controlled Ventilation (DCV) ... 12
Overview ... 12
Methodology ... 16
Results ... 19
Recommendations ... 22
Bibliography and Other Research ... 22

Construction Quality – Walls ... 24
Overview ... 24
Methodology ... 26
Results ... 28
Recommendations ... 29
Bibliography and Other Research ... 30

Water Heating Distribution Systems ... 31
Overview ... 31
Methodology ... 32
Results ... 36
Recommendations ... 38
Bibliography and Other Research ... 41

Appendix A – Nonresidential Lighting Models ... 1
Space Types ... 1
Analysis Assumptions ... 1

Appendix B – Rationale For Removing the 800 ppm CO_2 Requirement In California Title 24 ... 2
Issue ... 2
Findings ... 2
Recommendation ... 2
Background ... 2
Using CO_2 Concentration To Control Ventilation ... 3

Appendix C – Insulation Inspection Checklist ... 1

Tables

Table 1 – Space Types Analyzed ... 4
Table 2 – Comparison of Standard and 2nd Generation T-8 Lighting Systems ... 5
Table 3 – Comparison of T-5 HO and Metal Halide ... 6
Table 4 – Benefits of Metal Halide Pulse Start Lamps ... 6
Table 5 – Comparison of Halogen Infrared and CMH Lamps ... 7
Table 6 – Table 1-M – Whole Building Lighting Power Density Values (W/ft^2) ... 8
Table 7 – Table 1-N – Area Category Lighting Power Densities (W/ft^2) ... 9
Table 8 – Table 1-L – Lighting Control Adjustment Factors ... 11
Table 9 - Vendor Cost Data for CO_2 Based DCV as an Addition to Airside Economizers ... 15
Table 10 – Estimated Incremental First Cost ... 15

Table 11 - Simulation Results in Tabular Format 21
Table 12 – Current ACM Distribution System Multipliers (DSM)........ 32
Table 13 – Summary of DHW Use Quantities........ 33
Table 14 – Number of Weekly Fixture Draws by Plan 35
Table 15 – Pipe Lengths for Standard “Main/Branch” Piping Layout........ 36
Table 16 – Summary of HWSIM “Standard” Piping Layout Results 36
Table 17 – Summary of Pipe Insulation Savings and Economics........ 37
Table 18 – Summary of Recirculation Distribution Loss (DL) Results 38
Table 19 – Proposed ACM Distribution System Multipliers........ 40
Table 20 – Proposed ACM DSMs 40
Table A-1 – Auditorium........ 3
Table A-2 – Auto Repair 4
Table A-3 – Bank........ 5
Table A-4 – Church 6
Table A-5 – Classroom........ 7
Table A-6 – Clinic 8
Table A-7 – Convention Center........ 9
Table A-8 – Exhibition Hall 10
Table A-9 – Kitchen 11
Table A-10 – Retail........ 12
Table A-11 – Hotel........ 13
Table A-12 – Office........ 14
Table A-13 – Laundry 15
Table A-14 – Industrial High Bay........ 16
Table A-15 – Industrial Precision 17
Table A-16 – Airport Holdroom........ 18
Table A-17 – Air Ticket Counter 19
Table A-18 – Mail Sorting........ 20
Table A-19 – Police Hearing/Waiting 21
Table A-20 – Jail........ 22
Table A-21 – Senior Reading Sitting 23
Table A-22 – Housing Commons 24
Table A-23 – Civic Waiting Room 25

Figures

Figure 1 - UBC Exit Density Requirements........ 13
Figure 2 - Comparison of Schedules........ 18
Figure 3 - Cost Effective Breakpoints and Proposed Requirements as a Function of Zone Size and Occupant Density 20
Figure 4 - Cost Effective Breakpoints and Proposed Requirements as a Function of HVAC System Design OSA and Design OSA Per Area of Space........ 21
Figure 5 – Sample Hot Water Use Pattern........ 35
Figure 6 – HWSIM Results Summary for Standard Piping Layouts........ 37
Figure 7 – Relationship of SDLM to Floor Area 39
Figure B-1 – Correlation Between CO_2 Levels and Ventilation Rates 3

Introduction

This report contains the results of initiatives to upgrade and improve the 2001 California energy efficiency standards for residential and nonresidential buildings. The revisions will be adopted in 2003 for implementation in 2005.

Potential measure analysis initiatives and proposed standards changes were submitted and discussed at staff workshops on October 22, November 15, and November 16, 2001. The California Energy Commission (CEC) identified priority measures and funded analysis initiatives on a subset of these measures. Other parties have also funded analysis initiatives; however these analyses are not included in this document.

This document contains Part I of the report, which includes the measures analyzed under contract to the CEC that will be discussed in a staff workshop on April 23, 2002. Part II will include the measures analyzed under contract to the CEC that will be discussed in a workshop on May 30, 2002.

Summary of Measures

The following measures and modifications are addressed in this document:

- Nonresidential Lighting

  Updates to the Whole Building Lighting Power Density Values – Table 1-M. This measure reduces the allowed Lighting Power Density (LPD; Watts/ft^2) for several types of buildings. It updates the LPD values and adds a new whole building model to table 1-M.

  Updates to the Area Category Lighting Power Density Values – Table 1-N. This measure reduces the allowed Lighting Power Density (LPD; Watts/ft^2) for several types of area categories. It updates the LPD values and adds several new area categories to table 1-N.

  Modifies the Lighting Control Adjustment Factors – Table 1-L. This change eliminates credits for occupant sensors since they are commonly installed to meet the automatic shutoff requirement.

- HVAC – Demand Control Ventilation (DCV)

  Extends the Requirements for DCV §121(c)3 to Less Dense Occupancies. The current DCV requirement §121(c)3, which was adopted in the 2001 Energy Efficiency Standards for Residential and Nonresidential Buildings, is limited to Uniform Building Code (UBC) "high density" occupancies and spaces containing fixed seating with less than 10 ft^2/person and to systems that provide a minimum of 3,000 cfm outdoor air supply (OA) at design occupancy. Both of these limits are set higher than the cost effective threshold to provide the industry time to adjust to a new requirement for demand controlled ventilation. This initiative seeks to extend the DCV requirement to all cost effective occupant densities.

- Residential Construction Quality – Walls

  Improve Accuracy of Wall Modeling and Provide a Credit for High Quality Wall Construction. "Real" wall thermal performance is degraded from ideal performance by two factors: increased framing in the wall cavity and accounting for common insulation installation defects. This initiative analyzes how the effective insulation R-values differs from the labeled R-values, after the installation defects and the observed framing factors are considered. It recommends degrading the R-value of the cavity insulation in a neutral manner when industry standard methods are used, providing a credit when a high quality wall construction is independently verified. This represents only part of the study, since only walls are treated at this time. The study will eventually address roofs and floors.

- Water Heating Distribution Systems

  Improve Modeling Methodology. The last major changes to the water heating requirements were in 1992 and included a number of improvements. The current initiative attempts to further refine the methodology used in determining the domestic hot water energy load to better reflect actual conditions.

Specifically, the initiative proposes to change the distribution losses from a fixed multiplier to a multiplier that is a function of floor area and number of floors.

Update Distribution System Multipliers. This standards change revisits the distribution system multipliers, given the new costs of distribution systems and the new range of representative buildings developed to improve the modeling methodology. This initiative recommends disallowing certain distribution systems and altering other distribution system multipliers.

Review Adding Mandatory Requirement for Parallel Piping. Continued analysis will look at the cost effectiveness of parallel piping (or home run piping) and the possibility of adding it as a prescriptive requirement.

Acknowledgements

This project was completed by Eley Associates and its subcontractors. Charles Eley is the project manager for the contractor team. Andra Plagavko and Kimberly Got assisted with editing and report production. Credit for the specific technical chapters is acknowledged below:

- Nonresidential Lighting – The nonresidential lighting power analysis was completed by James Benya of Benya Lighting and by Larry Ayers of Eley Associates
- Demand Control Ventilation – This study was developed by Jeff Stein, Mark Hydeman, and Steve Taylor of Taylor Engineering. Incremental cost and estimated incremental labor data for this study was provided by Bob Levi and Jon Malkovich of Carrier Corporation, Kurt Wessels of Trane Company, Bill Bates of York International, and Mike Schell of Telaire.
- Construction Quality – Walls report was completed by Davis Energy Group, Inc. and Berkeley Solar Group. Field work was completed by Chitwood Energy Management and Amaro Construction as subcontractors to Davis Energy Group under the Commission’s Residential Construction Quality Assessment Project.
- Water Heating Distribution – The distribution system multipliers were calculated by Davis Energy Group and in particular by Dave Springer and Marc Hoeschele.

Nonresidential Lighting Power Density

Overview

Description

This proposed standards change reduces the allowed lighting power density (LPD) for several whole buildings types and area categories. It updates many of the W/ft² values in Tables 1-M and 1-N, adds several new area categories to Table 1-N, and adds one new whole building model to Table 1-M. The recommendation also includes deleting the credits for occupant sensors, daylighting controls, automatic time switch controls. A control credit of 25% is recommended for dimming ballasts.

Benefits

This measure will reduce lighting power for the affected building types, resulting in energy savings and reduced electric peak demand. Because the measure is based on readily available and cost effective lighting technologies, life cycle cost is reduced for building owners through both reduced energy costs and maintenance costs.

Environmental Impact

There is no negative environmental impact associated with this standards change. In addition to saving energy, some of the newer technologies last longer, which places less disposed lighting material into recycling and/or disposal. Furthermore, reduced energy use results in fewer atmospheric emissions.

Type of Change

The proposal would change the prescriptive lighting requirements for nonresidential buildings and modify the lighting power control credits.

Technology Measures

Lighting technologies needed to comply with this code change are readily available from multiple manufacturers. The cost effectiveness of lighting technologies that are driving this standards change is demonstrated below in the results section of this chapter.

Performance Verification

There are no performance verification or commissioning requirements associated with this code change. The process of code compliance and enforcement is unchanged.

Cost Effectiveness

The lighting technologies driving this code change are cost effective, as demonstrated in the results section of this chapter.

Analysis Tools

No analysis tools are needed for code compliance or enforcement.

Relationship to Other Measures

The best way to realize the benefits of super T-8 lighting systems is through the use of low ballast factor ballasts. Dimming ballasts are essentially ballasts with a variable ballast factor, but the upper end is 1.00 or higher. This means that there would be a penalty in using dimming ballasts with super T-8 lamps, since the dimming system would have a maximum power of about 64 W for a pair of lamps and the typical constant output low ballast factor system would have a maximum power of about 48 W for a pair of lamps. This is the reason that a control credit is recommended for dimming ballasts.

The T-5 HO lighting systems are quite sensitive to the ambient temperature surrounding the lamps. Their optimum temperature is about 95ºF (35ºC). This means that they achieve optimum performance in high spaces where the temperature near the ceiling is high. Alternatively, they may be used in enclosed luminaires, such that heat from the lamp maintains the high temperature.

Methodology

The lighting power density requirements in the Title 24 standards are based on lighting models. Each lighting model is described in terms of the following:

- Physical properties of the space such as the light loss factor, room cavity ratio (height, width, and length), and the reflectance of the ceiling, floor, and walls.
- Lighting design criteria, such as the desired footcandles for the visual tasks and the ambient surroundings.
- Characteristics of the lighting systems such as the coefficient of utilization (CU), the lamp/ballast efficacy and the types of luminaires and systems used within each space.

Each model is constructed using cost effective lighting technology. When there is an improvement in the lighting technologies that are the basis of the standards, then this is a justification for updating the lighting power density requirements. This happened in 1998 when electronic ballasts became the basis of the standard. In this study, there are four advances in lighting technology that are driving the changes in the allowed LPDs. These are:

1. T-8 second generation “super” fluorescent lamps.
2. Lighting systems employing the T-5 HO fluorescent lamps.
3. Metal halide “pulse start” lamps.
4. Metal halide “ceramic” lamps.

The lighting models shown in Appendix A are analyzed as part of this study. In each case the improved lighting technologies are applied and the allowed LPDs are calculated.

Table 1 – Space Types Analyzed

Auditorium	Kitchen	Air Ticket Counter
Auto Repair	Retail	Mail Sorting
Bank	Hotel	Police Hearing/Waiting
Church	Office	Jail
Classroom	Laundry	Senior Reading Sitting
Clinic	Industrial High Bay	Housing Commons
Convention Center	Industrial Precision	Civic Waiting Room
Exhibition Hall	Airport Holding Room	

Results

This section includes an analysis of the lighting technologies that are driving the changes in lighting power density. Each technology is shown to be cost effective using the CEC life cycle cost methodology[1].

[1] Life Cycle Cost Methodology, Eley Associates, March 11, 2002.

T-8 Second Generation "Super" Fluorescent Lamp

This super T-8 product includes the following enhancements over first generation standard T-8 lamps:

- Premium construction of cathode assembly designed for extended lamp life.
- Use of "barrier coat" phosphor, which returns unused UV radiation into the lamp and reduces lamp lumen depreciation.
- Use of optimized high CRI phosphor.
- Availability of "low power" lamps (30 W nominal versus 32 W standard).

The result of these enhancements is a lamp that generates more light and more maintained lumens per watt than common T-8 lamps. In the following table, note the significant improvement in mean lumens, which are measured at 40% of rated lamp life, or about half of the useful life of the lamp.

Table 2 – Comparison of Standard and 2nd Generation T-8 Lighting Systems

Lamp	Maker	Initial Lumens	Initial LPW*	Percent of Base	Mean Lumens	Mean LPW*	Percent of Base	Lamp Life, Hrs
Standard Lamps								
F32T8/7xx	Generic	2850	83	97%	2508	73	97%	20,000
F32T8/8xx ** (base)	Generic	2950	86	100%	2596	75	100%	20,000
2nd Generation Lamps								
F32T8/841/XP	Sylvania	3150	91	107%	2993	87	115%	24,000
F32T8/ADV8xx/ALTO	Philips	3200	93	108%	3040	88	117%	24,000
F32T8XL//IS/WM/SPxx	GE	2850	97	113%	2675	91	121%	25,000

Table notes

* As used in a two lamp, instant start electronic ballast system.

** The first generation, 8xx-color lamp was used in previous Title 24 models by CEC staff.

The first cost differential between 2nd generation lamps and the conventional T-8 lamp is about $2 per lamp. If it is assumed that the lamp is replaced every five years, the present value of the premium lamp over a 15-year time horizon is $6.46. If it can be shown that the present value of the energy savings over the same period is greater than this, then the premium lamp is cost effective.

Assuming a low-ballast factor for the 2nd generation so that light output is the same for super T-8 and conventional T-8 lamps, the power reduction is about 4.5 W/lamp. Assuming 3,500 hours of annual lighting operation, the annual savings are 15.75 kWh/year per lamp. The present value of these savings is $21.58, based on CEC economic assumptions. This is about three times greater than the present value of the costs, so the super T-8 lamps are convincingly cost effective. Analysis shows that the super T-8 lamps would be cost effective with as little as 1,000 hours of annual operation.

The benefits of this technology are applied to the area models (see Appendix A) by assuming a 15% reduction in power required for full-size fluorescent lighting systems.

T-5 HO Lamp

The T-5 HO lamp can be used singly or in groups to produce a surprising amount of light. Because peak output is reached at 95ºF (35ºC), it operates at optimum temperature when suspended from high ceilings in gyms or big box retail stores. Combining six lamps in a single luminaire produces light comparable to a metal halide lamp, and optical control makes this a successful alternative to high bay HID lamps.

Table 3 is a comparison of high bay T-5 HO to standard probe start and modern pulse start metal halide lamps for general lighting:

Table 3 – Comparison of T-5 HO and Metal Halide

Lamp Type	Lumens per lamp	Lamps per luminaire	Mean Lumens per Lamp	Total Mean Lumens per Luminaire	Coefficient of Utilization (CU)	Luminaires per 10,000 ft² (50 fc)	Input Watts per Luminaire	Lighting Power Density (W/ft²)
MH400 base	40000	1	26000	26000	0.82	24	458	1.10
MH400PS	42000	1	31000	31000	0.82	20	425	0.85
MH400PS	42000	1	31000	31000	0.82	20	452	0.90
F54T5HO	5000	6	4500	27000	0.83	22	360	0.79

The above are based in open HID fixtures and lensed fluorescent fixtures. The first pulse start luminaire uses a reactor 277 V ballast. Lamp data is from Sylvania. Ballast data is from Advance. Luminaire data is from Lithonia and Holophane.

Based on costs obtained from Lithonia Lighting for their industrial HID line, the contractor net cost of a 400 watt metal halide luminaire ranges from $150 to over $300; the T-5 HO luminaire cost from 1st Source, Holophane, and Williams ranges from $200 to over $300. Since the cost is about the same, and it is possible to reduce the lighting power density from 1.1 W/ft² to less than 0.80 W/ft² without compromising quality, the technology is clearly cost effective. In addition, the T-5 HO contains three ballasts that permit stepped dimming without additional cost, and the immediate restrike of the T-5 HO lamps permit their operation as emergency lighting without the need for auxiliary lamps. The lighting system may also be dimmed with the right ballast.

The benefits of this technology are applied to area models (see Appendix A) by assuming a 20% reduction in power for appropriate applications that were previously modeled using metal halide. This technology is not suitable for high bay spaces over about 40 ft due to photometric reasons, and it is it is not recommended in applications where the temperature of the lamp will drift more than about 10ºF from the optimum 95ºF.

Metal Halide Pulse Start Lamp

Although pulse start metal halide is a common technology in lower wattage lamps and all HPS lamps, MH pulse start technology for lamps over 150 W did not become popular until the mid-1990s. This is largely due to the lack of standardization of lamps and an information gap about the benefits of the products. The following table illustrates the benefits of pulse start metal halide lamps:

Table 4 – Benefits of Metal Halide Pulse Start Lamps

	Initial Lumens		Mean Lumens		Mean LPW				Pulse
Lamp Watts	Probe	Pulse	Probe	Pulse	Probe	Pulse	Life Probe	Pulse	Power Needed
175	13600	17000	8800	12500	43	61	10,000	15000	70%
250	20800	23000	13500	17000	46	58	10,000	20000	79%
400	36000	41000	23500	31000	52	69	20,000	20000*	76%

Table notes

* Indicates daily cycling; lamps operated continuously with weekly on/off cycle can last up to 30,000 hours. Source: GE Lighting.

All vertical burning position.

Pulse start lamps are commonly available from all four major HID lamp companies and are standard offerings from most luminaire manufacturers. According to one direct mail order company (RUUD Lighting), there is almost no cost difference between pulse start and probe start metal halide luminaires. With no cost premium, the benefits of the pulse start technology make the technology obviously cost effective.

The benefits of this technology are applied to the area models (see Appendix A) by assuming a 20% reduction in power required for lighting systems that were previously modeled using probe-start metal halide. This technology is useful in every location that standard metal halide is used. It has extremely limited dimming potential, typically by a two level dimming step (high/low).

Ceramic Metal Halide (CMH) Lamp

The ceramic metal halide (CMH) lamp was first introduced in the early 1990s and represents a significant advance in metal halide lamp color. By creating a light color similar to halogen, it makes metal halide applicable in locations where compact fluorescent, due to lack of candlepower, is not suitable.

CMH lamps are made in 35/39 W, 50 W, 70 W, 100 W, and 150 W lamps for general and display applications, and in recently unveiled products, 250 W and 400 W lamps for general lighting. The 250 W and 400 W lamps replace ordinary metal halide or HPS, but offer no energy benefits. However, energy benefits are achieved when using CMH instead of halogen lamps for downlighting, wall washing, and retail display. Table 5 compares halogen infrared and CMH lamps.

Table 5 – Comparison of Halogen Infrared and CMH Lamps

Lamp	Life, hours	CBCP, initial	Lumens, initial	MBCP	Lumens, mean	Input Watts	MLPW	Mean MBCP/W
100PAR/HIR/FL (GE)	3000	6300	2200	5985	2090	100	21	60
CDM35PAR30L/M/FL (Philips)	10000	7400	2000	5920	1600	45	36	132
CBCP Center beam candlepower			MBCP Maximum beam candle power					

Table 5 is a realistic example of the displacement of halogen lighting by HID. The added cost of a CMH lamp and ballast over a halogen lamp in typical display lighting is about $100 per lamp[2]. Replacement and maintenance costs for the two technologies are about the same and these cost differences can be ignored, e.g., halogen is less expensive to replace, but must be replaced more often. The power savings between the two lamps is about 55 W, and assuming 5,000 hours of operation, the present value of energy savings are about $375, almost four times greater than the cost premium.

The benefits of this technology are applied to the area models (see Appendix A) by assuming a 10% reduction in power required for certain lighting systems that were previously modeled using halogen. The inability to dim CMH will limit some applications. Spaces with frequently used controls, especially motion sensors, are not suitable for CMH.

Recommendations

It is recommended that the standards be changed in the following manner:

- Substitute revised tables 1-M and 1-N, attached, for the existing tables. See Table 6 and Table 7 below.
- Add definitions for civic facilities, housing, public and commons areas, prisoner holding cell or jail, police or fire stations, post office, and transportation facilities to Section 101.
- Modify the lighting control credits to eliminate occupant sensors and timers.

[2] This is based on prices for a three lamp retail display luminaire from Lightolier (Fall 2001).

Lighting Power Density

Table 6 – Table 1-M – Whole Building Lighting Power Density Values (W/ft²)

	Allowed Lighting Power	
Type Of Use	**Current**	**Proposed**
General commercial and industrial work buildings		
High bay†	1.2	1.1
Low bay	1.0	1.0
Grocery stores	1.5	1.5
Hotel*	N/A	1.7
Industrial and commercial storage buildings	0.7	0.7
Medical buildings and clinics	1.2	1.0
Office buildings	1.2	1.1
Religious facilities (church)	1.8	1.6
Auditoriums	1.8	1.5
Convention centers	1.4	1.3
Restaurants	1.2	1.2
Retail and wholesale stores	1.7	1.5
Schools	1.4	1.2
Theaters	1.3	1.3
All others	0.6	0.6

* New model
†Space assumptions revised from 1998 model

Table 7 – Table 1-N – Area Category Lighting Power Densities (W/ft²)

	Allowed Lighting Power	
Primary Function	**Current**	**Proposed**
Auditorium	2.0*	1.7*
Auto repair	1.2*	1.1
Bank/financial institution	1.4*	1.2*
Civic facilities (town hall, court house)‡	NA	1.4*
Classrooms, lecture, training, vocational room	1.6	1.2
Commercial and industrial storage	0.6	0.6
Convention, conference, multipurpose and meeting centers	1.5*	1.4*
Corridors, restrooms, stairs and support areas	0.6	0.6
Dining	1.1*	1.1*
Electrical, mechanical rooms	0.7	0.6
Exercise center, gymnasium	1.0	1.0
Exhibit, museum	2.0	2.0
General commercial and industrial work:		
High bay†	1.2	1.1
Low bay	1.0	1.0
Precision†	1.5	1.3
Grocery store	1.6	1.6
Housing, public and commons areas		
Multi-family‡	NA	1.0
Dormitory (school and senior housing) ‡	NA	1.5
Hotel function area	2.2*	2.0*
Kitchen, food preparation	1.7	1.6
Laundry	0.9	0.9
Library		
Reading areas	1.2	1.2
Stacks	1.5	1.5
Lobbies:		
Hotel lobby	1.7*	1.7*
Main entry lobby	1.5*	1.5*
Reception/waiting	1.1*	1.1*
Locker/dressing room	0.8	0.8
Lounge/recreation	1.1	1.1
Malls, arcades and atria	1.4*	1.2*
Medical and clinical care	1.4	1.2
Office	1.3	1.2
Prisoner holding cell or jail‡	NA	1.0
Police or fire stations‡	NA	1.3
Post office‡	NA	1.6
Religious worship (church)	2.0	1.9*
Retail sales, wholesale showrooms	2.0	1.8
Transportation facilities (baggage-ticket-waiting)‡	NA	1.2
Theaters:		
Motion picture	0.9	0.9
Performance	1.4*	1.4*
All other	0.6	0.6

*Chandelier allowance can be added to these values
†These models were slightly modified from 1998 models
‡New models

Definitions

The following definitions are added to Section 101:

Civic facilities include areas within government buildings that are not offices, corridors, rest rooms, or any other specific category in Table 1-N. Civic facilities include, but are not limited to, waiting rooms, jury rooms, courtrooms, hearing rooms, council or board rooms, council chambers (except offices), and civic lobbies.

Housing, public and commons areas are areas within housing facilities as follows:

- In mutli-family housing, these areas include hallways, lobbies, commons areas such as community rooms, exercise and recreation spaces, and other common spaces of the building except offices, stairwells, kitchens, dining rooms, toilet rooms, locker rooms, storage rooms, or mechanical rooms.
- In multi-family housing specifically designed for seniors, these areas include community rooms, dining rooms, multipurpose rooms, reading rooms, corridors, exercise and recreation rooms, and other spaces of the building except offices, kitchens, libraries, toilet rooms, locker rooms, storage rooms, or mechanical rooms. In order to qualify as senior multifamily housing, the project shall include three or more of the following facilities: skilled nursing, assisted living, Alzheimers care, hospice, and common dining.
    - Skilled nursing means having facilities equipped to provide medical care to non-ambulatory residents, meeting California law.
    - Assisted living means having facilities to provide limited medical care and assistance to disabled and/or non ambulatory residents, meeting California law.
    - Alzheimers care means providing secured facilities specifically designed for the care and protection of persons suffering from Alzheimers and dementia, meeting California law.
    - Hospice means having facilities to provide limited medical care for the terminally ill in a residential setting. meeting California law.
    - Common dining means providing a community cafeteria or dining facility for residents and guests.
- In dormitories, these areas shall include community rooms, dining rooms, multipurpose rooms, reading rooms, corridors, exercise and recreation rooms, and other spaces of the building except offices, libraries, toilet rooms, kitchens, locker rooms, storage rooms, or mechanical rooms.

Prisoner holding cell or jail includes incarceration spaces, lockups, jails, and related support spaces such as prisoner interview rooms.

Police or fire stations includes garages and maintenance areas for emergency vehicles and equipment; common meeting and training rooms, lobby and receiving areas, waiting areas, hearing rooms, and spaces of the building except offices, libraries, toilet rooms, kitchens, locker rooms, storage rooms, or mechanical rooms.

Post office includes the areas within a building in which the US Postal Service receives, sorts, dispenses, or otherwise services mail, including public waiting, counter service and self-service areas, and other spaces of the building except offices, libraries, toilet rooms, kitchens, locker rooms, storage rooms, or mechanical rooms.

Transportation facilities includes areas within airport, bus, passenger rail, mass transit, or passenger liner terminals or concourses such as lobbies, ticketing, baggage claim, holdrooms, information and help areas, and related facilities except dining rooms, retail, offices, libraries, toilet rooms, kitchens, locker rooms, storage rooms, or mechanical rooms. If freestanding with a transportation facility, a specific use type, e.g., retail or dining, shall be permitted as if it were enclosed by a ceiling high partition or demising wall.

Control Credits

Occupant sensors and time clocks should be deleted from the lighting power control credits table (Table 1-L in the standards). The reason is that §131 already requires automatic shutoff equipment even if the building is less than 5,000 ft^2. The recommendation is to eliminate all controls credits for controls that are now mandatory or a mandatory option. However, fluorescent dimming ballasts are a technology that needs to be encouraged, so a control credit of 25% is recommended for any fluorescent lighting system using dimming ballasts with any type of controller (daylighting, manual, etc.). This recommendation is based on the ratio of power used by a typical dimming ballast (at full output) to a low power regular ballast.

Table 8 below is a replacement table for Table 1-L of the standards.

Table 8 – Table 1-L – Lighting Control Adjustment Factors

Type Of Control	**Type Of Space**			**Factor**
Incandescent dimming systems				
Manual	Hotels/motels, restaurants, auditoriums, theaters			0.10
Multiscene programmable	Hotels/motels, restaurants, auditoriums, theaters			0.20
Fluorescent dimming ballasts				0.25
Automatic daylighting controls (stepped/dimming)				
Windows		**Window Wall Ratio**		
	Glazing Type	**< 20%**	**20% to 40%**	**> 40%**
	VLT ≥ 60%	0.20/0.30	0.30/.040	0.40/0.40
	VLT ≥ 35 and < 60%	0/0	0.20/0.30	0.30/0.40
	VLT < 35%	0/0	0/0	0.20/0.40
Skylights		**Percentage of Gross Exterior Roof Area**		
	Glazing Type	**< 1%**	**1% to 3%**	**> 3%**
	VLT ≥ 60%	0/0.30	0.15/0.40	0.30/0.40
	VLT ≥ 35 and < 60%	0/0.20	0/0.30	0.15/0.40
	VLT < 35%	0/0.10	0/0.20	0/0.30

Bibliography and Other Research

Data for lamp and ballast information was obtained from the following websites:

www.gelighting.com

www.sylvania.com

www.philips.com

www.advancetransformer.com

Models are based on those contained in July 1997 models developed by Mazi Shirakh of the California Energy Commission, using methods described at www.iesna.org as used for LPD models for 90.1-1999.

Data regarding 90.1-1999 was obtained from IESNA LEM-1-1999 (Illuminating Engineering Society of North America, *IES Recommended Procedure for Lighting Power Limit Determination* LEM-1-1999, New York, NY, 1999).

The *Advanced Lighting Guidelines 2001* models demonstrate significant potential reductions in lighting power if proper lighting methods are employed (New Buildings Institute, *Advanced Lighting Guidelines 2001*, White Salmon, WA, 2001).

Demand Controlled Ventilation (DCV)

Overview

Description

This initiative seeks to expand the current requirement for demand ventilation controls. Specifically, this initiative is designed to address the following issues:

- Extending the requirements for DCV §121(c)3 to less dense building occupancies.
- Determining the cost effective, system size threshold for the requirement.
- Updating the control requirements for CO_2 sensors based on the best information available in the research and standard communities.

Extending the requirements to cover multiple zone systems is also investigated, but there are several reasons that their inclusion is not recommended at this time:

- There are not adequate modeling tools or research to support this effort. The effectiveness of DCV in multiple zone systems depends strongly on the diversity of the spaces and the ability of the system to take advantage of recirculated air from over-ventilated spaces. The results will be very application specific.
- It requires direct digital control (DDC) at the zone level to work. Since there is no requirement in the standards for DDC controls, these controls would have to be cost justified along with the DCV system.
- Adequate existing guidelines do not exist on how to sequence the controls for the zone terminal units and outdoor air dampers in response to changes in the space CO_2 levels.

The current DCV requirement §121(c)3, which was adopted in the AB 970 standards, is limited to UBC "high density" occupancies and spaces with fixed seating with less than 10 ft^2/person. The existing requirement is limited to systems that provide a minimum of 3,000 cfm outdoor air supply (OA) at design occupancy. Both of these limits are set higher then the cost effective threshold to provide the industry time to adjust to a new requirement for DCV. The life cycle cost study that was completed for the AB 970 requirement indicates that it might be cost effective for a wider variety of less dense occupancies such as classrooms, airport or train terminals, and others.

Three threshold occupant densities are of particular interest in this effort[3]:

1. 14 ft^2/person covers the UBC classification for "high density" assembly spaces (Figure 1, usage category 3).
2. 30 ft^2/person covers the UBC classification for less dense assembly spaces (Figure 1, usage category 4).
3. 40 ft^2/person covers the UBC classification for classrooms (Figure 1, usage category 7).

These three thresholds represent half the occupant densities (i.e. half as many people) of the tables in Chapter 10 of the Uniform Building Code (UBC) for calculation of exiting requirements. Section §121(b)2B of Title 24 uses half of the UBC exiting occupant densities as the minimum occupant density for purposes of ventilation requirements. These three densities are of interest because they represent many typical assembly spaces including theaters, reception areas, ballrooms, stadiums, train and air terminals, and classrooms.

[3] §121(b)2B refers to Chapter 10 of the UBC for calculation of the occupant density where fixed seating is not provided. "*For spaces without fixed seating, the expected number of occupants shall be assumed to be no less than one half the maximum occupant load assumed for exiting purposes in Chapter 10 of the UBC.*" The three thresholds used in this study are the thresholds for the three densest occupancies in this section of the UBC.

USE[1]	MINIMUM OF TWO EXITS OTHER THAN ELEVATORS ARE REQUIRED WHERE NUMBER OF OCCUPANTS IS AT LEAST	CUPANT LOAD FACTOR[3] (square feet) × 0.0929 for m²
1. Aircraft hangars (no repair)	10	500
2. Auction rooms	30	7
3. Assembly areas, concentrated use (without fixed seats) Auditoriums Churches and chapels Dance floors Lobby accessory to assembly occupancy Lodge rooms Reviewing stands Stadiums	50	7
Waiting area	50	3
4. Assembly areas, less-concentrated use Conference rooms Dining rooms Drinking establishments Exhibit rooms Gymnasiums Lounges Stages	50	15
5. Bowling alley (assume no occupant load for bowling lanes)	50	4
6. Children's homes and homes for the aged	6	80
7. Classrooms	50	20
8. Congregate residences	10	200
9. Courtrooms	50	40
10. Dormitories	10	50
11. Dwellings	10	300
12. Exercising rooms	50	50
13. Garage, parking	30	200
14. Hospitals and sanitariums—Health-care center	10	80
Nursing homes Sleeping rooms	6	80
Treatment rooms	10	80
15. Hotels and apartments	10	200
16. Kitchen—commercial	30	200
17. Library reading room	50	50
18. Locker rooms	30	50

Figure 1 - UBC Exit Density Requirements

In order to evaluate this measure, cost data is collected on demand-based ventilation controls and simulated economizer performance with and without DCV for several different assumptions of occupant density and across all climate zones. DCV is simulated by having the minimum outdoor air supply modulate with the occupancy to maintain 15 cfm/person at all times. The simulated base case of no DCV has a minimum outdoor air supply fixed at 15 cfm/person based on design occupancy.

The analysis shows that DCV is cost effective in the target occupant densities where airside economizers are required for single zone systems. As previously noted, an extension to multiple zone systems is not being proposed at this time.

In addition to the analysis for cost effective thresholds for DCV, documented research and issues support the removal of the 800 ppm set point for CO_2-based DCV systems. Research consensus is that higher levels of CO_2 are not a health hazard and that the CO_2 set point should be the equivalent of 15 cfm/person, a slightly higher number. Although a higher set point will result in a higher level of contaminants in the space, the greater of two minimums, a) the threshold outside air minimum of 15 cfm/person, and b) the minimum set point for building based contaminants, is considered to be reasonable by relevant code and standard authorities (ASHRAE 62-2001, ASHRAE 90.1-1999, and the 2000 International Mechanical Code).

Benefits

DCV saves energy and reduces peak demand. DCV dynamically reduces the amount of outside air when fewer than the design number of people are in a zone. An additional benefit of DCV is the ability of occupants and system operators to monitor CO_2 concentration in a zone and therefore receive feedback on HVAC system ventilation performance.

Environmental Impact

Beneficial environmental impacts are reduced electricity (energy and demand) and natural gas consumption.

When properly tuned, DCV insures that code minimum ventilation rates are maintained at all times. It acts to reduce over-ventilation of spaces when they are not fully occupied.

DCV systems increase the concentration of bioeffluents and building-borne contaminants in the space when partially occupied. However, as documented in this study, these contaminant levels are maintained at acceptable concentrations based on research, and consensus of code and standard organizations.

Type of Change

The proposed measure is a modification of an existing mandatory measure, §121(c)3. It extends the current coverage of the DCV requirement to include a wider range of occupancies. It also relaxes the ventilation requirements for CO_2-based DCV systems, which improves energy savings.

The change requires minimal modification of the standards, nonresidential manual, and ACM modeling procedures.

The changes to the standards are described below. The ACM change models a scheduled outdoor air minimum position based on 15 cfm per person and the occupant schedule. The nonresidential manual updates describe how to implement demand-based ventilation controls with single zone system economizers. The nonresidential manual will also provide guidance on how to select the design set points for these controls, performance verification during startup, and field calibration of the sensors.

Measure Availability and Cost

CO_2 sensors and controls are readily available from several manufacturers in quantities to satisfy current demand. Because market penetration to date has been fairly limited, the industry was surveyed to determine the difficulty of scaling up production. It was found that with a lead time in the three to six month range, manufacturers could produce sensors far in excess of California's requirements.

CO_2 sensors and controls are integrated into thermostats and economizers as OEM products by some of the major air-conditioning manufacturers. Sensors available on the market today have a self-calibrating feature and are inherently stable enough to ensure that recalibration is required at intervals exceeding five years[4]. One sensor manufacture has bundled their sensor into temperature sensors for packaged equipment and into economizer controllers. CO_2 controls are available as a factory-installed option on packaged rooftop equipment from several manufacturers, including all the major manufacturers.

CO_2 sensors are primarily electronic devices with microprocessors that are very simple to produce and can be set up at almost any good electronics manufacturing company. Build time and calibration takes a few hours. At least three large, well-financed companies are primary manufacturers involved in this market and can respond easily to an increase in sensor demand resulting from this requirement. These manufacturers provide product to all major HVAC and controls companies, who in turn, will be placing orders well in advance of this

4 One manufacturer maintains that this self calibration feature will indeed last the life of the sensor and control. They are considering extending their warranty to the life of the system.

requirement. According to the largest commercial manufacture, the most conservative lead-time on components is approximately three months. One manufacturer's parent corporation produces over 2,000,000 sensors annually. The electronics and optical elements for CO_2 and smoke detectors are very similar on a manufacturing basis. That manufacturer has four world-wide plants and plenty of excess capacity – with six to eight months warning, they can easily produce hundreds of thousands of sensors, far in excess of California's requirements.

In calculating the life cycle cost, the baseline comparison condition is no DCV device and a fixed minimum outside air quantity. As mentioned above, market penetration to date is fairly limited. Therefore, the proposed requirement significantly increases market penetration and is likely result in both cost reductions and advancements in technology.

Several DCV system vendors provided for the most recent cost data on DCV kits for several sizes of packaged rooftop equipment. Three packaged rooftop equipment vendors responded with incremental costs.

Table 9 - Vendor Cost Data for CO_2 Based DCV as an Addition to Airside Economizers

	Incremental Cost ($/system)	**Incremental labor (hrs/system)**
Vendor A	$310	0.5
Vendor B	$400	0.5- 1.0
Vendor C	$700	8-16

Vendor C is an outlier. Their prices are artificially high due to their unfamiliarity with these systems. Given the responses from Vendors A and B as well as the expected reductions in cost and labor as usage and familiarity grow, a reasonably conservative estimate of the incremental first cost is as follows:

Table 10 – Estimated Incremental First Cost

Parts: $300 (+25% contractor markup)	$375
Labor: Two hours @ $100/hr	$200
TOTAL	$575

Although Vendors A and B estimated between half to one hour of labor for installation and start-up, labor in this table is conservatively estimated at two hours.

Technology Measures

Useful Life, Persistence and Maintenance

According to two manufacturers, their product will last 15 years. They claim that the calibration of the sensor is accurate over the life of the sensor, although it is only currently warranted for five years. Several manufacturers have a recommended calibration interval of five years or greater.

CO_2 sensors are normal electronic devices that have a useful lifetime similar to other electronic base sensors and controls. Using readily available commercial components, one manufacturer recently completed a mean time between failure (MTBF) analysis for a customer and found it to be 15 years. Sensor stability and self-calibration features integrated into sensor design prevent degradation of the sensor. For sensors without this feature, the manufacturers provide calibration procedures, recommended calibration schedules, and calibration kits.

Many CO_2 sensors devices have integrated some level of self-diagnostics to identify potential problems. The output of the microprocessor-based CO_2 sensors can be analog or digital. An example of a self-diagnostic failure indication from an analog sensor (the range of which is 0-10 VDC or 4-20 mA) would be either sending out the maximum signal or providing zero output. Since ambient CO_2 levels are always above 350 to 400 ppm, a zero signal is an automatic indication of a sensor failure. When connected to a building control system or air handling unit controller, this zero signal can be interpreted as a fault, with the appropriate action then taken. A failure indication from a digital communicating sensor (e.g., Lonworks) is either a fault signal or a failure to communicate, both of which allow for the appropriate response from the ventilation control system.

Given the number ways different control systems handle the non-standardized CO_2 signals, any fail-safe considerations have to be integrated into the controller. Many controls companies have already integrated an automated control systems response, as well as an alert for human intervention when a sensor appears to be providing incorrect readings.

Sensor failure is only an issue when the system is not in economizer mode, when sensor error would adversely affect indoor air quality. For example, if a space is heavily occupied but the sensor underestimates CO_2 concentration, then the system may not bring in adequate ventilation.

Although the description above focuses on how a CO_2 sensor may fail, CO_2 sensors can improve the overall functioning of a system by indicating failure of other mechanical system components, such as a frozen outside air damper or leaking furnace heat exchanger.

Performance Verification

The TAB contractor calibrates the controls and damper positions during startup. Kits with calibrated CO_2 concentrations are available at approximately $100 each that can be used to field calibrate the sensors if necessary. These kits are available from a number of sources including the DCV manufacturers, industrial sensor manufacturers, and industrial gas companies. At least two manufacturers, Honeywell and Telaire, have sensors with a maximum guaranteed drift over a five-year period. These sensors are factory calibrated.

The performance verification paper proposes adding two requirements to improve the performance of DCV devices:

- Certification by either the manufacturer or installing contractor that the CO_2 sensor has been calibrated on installation.
- Provision of recommended calibration procedures and intervals from the manufacturer.

Cost Effectiveness

This measure is justified through a detailed life cycle cost analysis. See the life cycle cost analysis section below.

Analysis Tools

DOE-2.2 with the eQuest interface is used to analyze this measure.

Relationship to Other Measures

This measure is tied to the prescriptive requirement for airside economizers (§144(e)). The incremental cost of implementing this measure assumes that the cost for the outside air damper actuator and minimum position potentiometer are already included in the base case. These items are an integral part of an airside economizer.

Methodology

Simulation Using DOE-2 Office Model in California

Ninety-six simulations were performed to cover all the permutations of the climate, density, and minimum outside air control variables:

- Sixteen California climate zones.
- Three occupant densities:
    - 14 ft^2/person (Title 24 ventilation density corresponding to UBC high density classification).

  - 20 ft^2/person (This was a mistake, as it was supposed to be 30 ft^2/person corresponding to the UBC less dense assembly space classification. Since the results were cost effective at 40 ft^2/person, this point is not significant).
  - 40 ft^2/person (Title 24 ventilation density corresponding to UBC classroom classification).
- Two outside air schemes: DCV versus Fixed Minimum.

The eQuest interface generates a Title 24 (2001) compliant building with schedules based on the ACM manual.

Modeling Assumptions

- A 45 ft X 45 ft interior zone space with no windows, floor or roof load. Since the only difference between the base case and DCV runs is the minimum outdoor air set point, exterior loads are not a factor in the savings. The economizer in each case is fully functional. The only load that differs between the runs is the heating and/or cooling required for the different outside air ventilation rates. The dampers are modeled at minimum position unless the CO_2 sensor high limit switch has triggered or the economizer carries a greater percentage of the cooling load.
- Occupancy schedule. See discussion below.
- Minimum outside air. Two cases are run for each density:
  - No DCV – The minimum damper position is fixed at 15 cfm/person times the design occupancy
  - DCV – The minimum damper position is fixed at 15 cfm/person times ½ the design occupancy. Refer to the discussion below about occupant diversity and schedules.
- Lighting peak power of 1.5 W/ft^2. This is the ACM default for conference centers. LPD is varied each hour and day of the week using the ACM nonresidential lighting schedule. This schedule has the lights at 90% for most of the time.
- Equipment peak power of 1.0 W/ft^2. This is the ACM default for conference centers. The EPD is varied each hour and day of the week using the ACM nonresidential equipment schedule.
- Zone heating set point of 70°F with a 55°F setback, scheduled per the ACM nonresidential heating schedule.
- Zone cooling set point of 74°F with a 95°F setup, scheduled per the ACM nonresidential cooling schedule.
- System operation from 6 AM to 9 PM weekdays, 6 AM to 3 PM Saturdays, and off on Sundays, per the ACM non-residential fan schedule.
- A single zone served by a packaged single zone (DOE-2 type PSZ) unit with a 57°F minimum supply air temperature and a constant-volume draw-through fan.
- Cooling EIR, furnace HIR and fan power rating are all defaulted to Title 24 minimums.
- Fixed dry-bulb economizer with dry-bulb high limit set to 75°F.
- Cooling capacity is auto-sized with a 1.10 sizing ratio.
- Supply CFM is calculated based on steady-state design LPD, EPD and peak occupancy.
- Thermostat throttling range = 4.0. This is the ACM default for this system type.
- ACM default mass assumptions.

Occupancy Schedule

A number of occupancy schedules from ASHRAE Standard 90.1-1999 (public review draft 1), Title 24 ACM manual, and library schedules from the eQuest program are investigated. These are detailed below. For each of these schedules, the average occupancy is examined. The average occupancy varies from 40% to 70%. Since this measure will cover facilities that are likely to have their peak occupancies at different times of the day (and during different utility rate periods), the conservative assumption of using a flat occupancy schedule of 50% full occupancy during all hours of operation is used.

The examined schedules include the following:

- ASHRAE 90.1-1999 Schedule "C" (used for museum general exhibition, theater auditorium seating area, theater lobby, supermarket, library, etc.). During the hours of fan operation, this schedule has an average occupancy of 50%.
- ASHRAE 90.1-1999 Schedule "I" (used for assembly, religious, theater performing arts seating, etc.) During the hours of fan operation, this schedule has an average occupancy of 54%.
- ASHRAE 90.1-1999 Schedule "B" (used for hotel banquet, motel dining, cafeteria, etc.) During the hours of fan operation, this schedule has an average occupancy of 51%.
- ASHRAE 90.1-1999 Schedule "D" (used for classroom, laboratory, etc.) During the hours of fan operation, this schedule has an average occupancy of 52%.
- eQuest – Secondary School Schedule. During the hours of fan operation, this schedule has an average occupancy of 41%.
- ACM Nonresidential Occupancy Schedule. This schedule only achieves 50% peak occupancy at any time and 35% average occupancy at all "normally occupied" times but is multiplied by the full UBC exiting density. Since the three threshold occupant densities are based on half the UBC exiting density numbers, the ACM schedule is rescaled by a factor of two. The resulting average occupancy is 70%.

All of these schedules are compared in Figure 2 below.

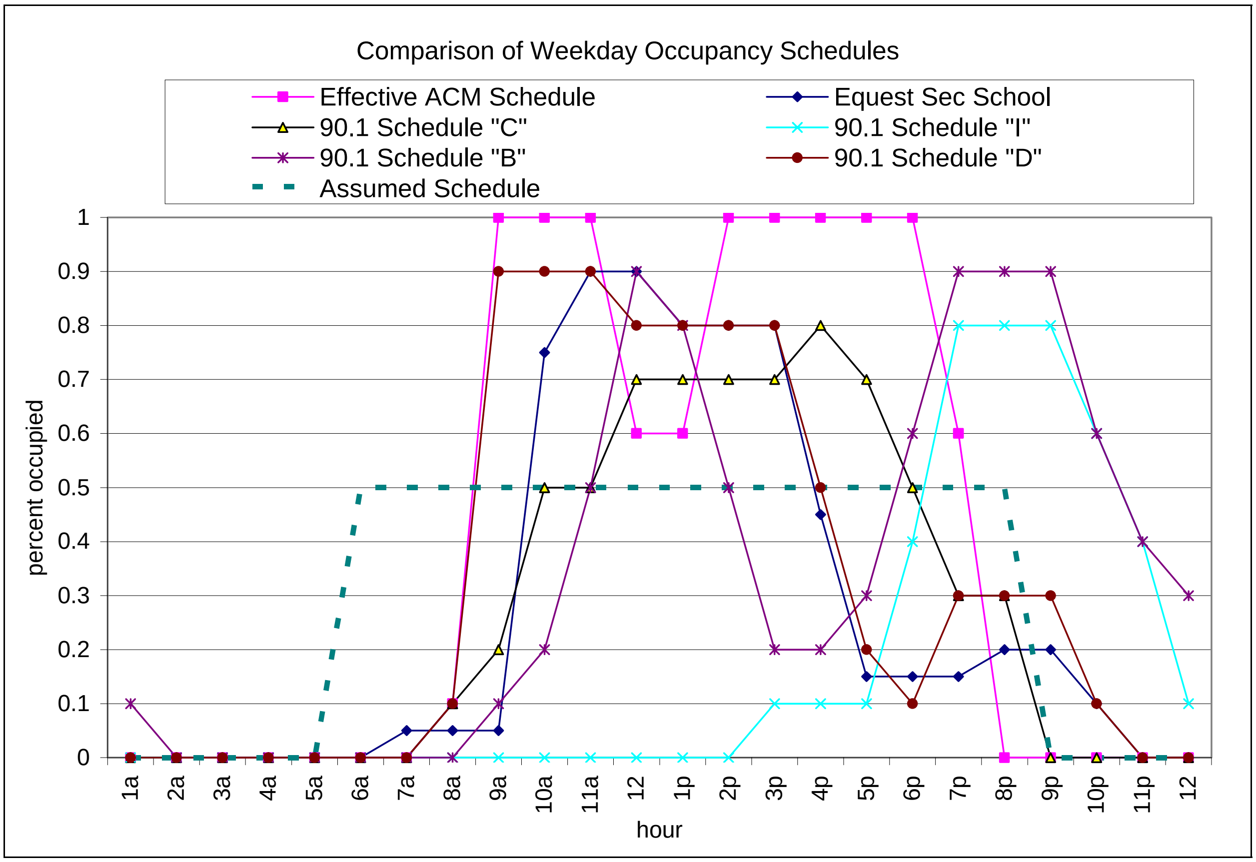

Figure 2 - Comparison of Schedules

Economic Criteria

The annual heating and cooling energy amounts for each run are converted to a net present value using the CEC standard amounts listed below. These data are taken from the "Utility Cost Forecasts, Years 2005 through 2035" document provided by Eley Associates.

- $1.37 as the present value of a kilowatt-hour saved over a 15-year life.
- $7.30 as the present value of a therm saved over a 15-year life.

The breakpoint where DCV becomes cost effective is the point at which the net present value of the energy savings exceeds the incremental first cost.

It is possible that a time-dependant valuation (TDV) analysis (as opposed to non-TDV approach used in this analysis) would show that DCV is even more cost effective because much of the potential benefit of DCV comes at the hottest periods of time. A non-TDV analysis is used to be conservative.

Results

Simulation and LCC Results

The results of the analysis for single zone HVAC systems are shown in Figure 3, Figure 4, and Table 11 below. Figure 3 and Figure 4 are the same results presented in different units. The results indicate that DCV systems are cost effective in all climates on single zone systems whenever airside economizers are required if the design area per person is 40 ft^2/person or less (i.e. design minimum outdoor air >= 0.375 cfm).

Figure 3 and Figure 4 show the life cycle cost analysis breakpoint for each of the 16 climate zones for each of the three occupant densities (14 ft^2/person, 20 ft^2/person, and 40 ft^2/person). The horizontal axis is the occupant density expressed either in ft^2/person (Figure 3) or the equivalent design ventilation in cfm of outside air per ft^2 of space at 15 cfm per person (Figure 4). The vertical axis is the AC unit size expressed either in the zone size (Figure 3) or design cfm of outside air (Figure 4). In addition to the results for the 16 individual climates, a dashed line indicates the weighted average of the results of all climate zones. The weighting factors are based on projected new construction (AB970 Impact Analysis Report).

The solid line at the top of each figure shows the approximate boundary of the existing air-side economizer requirement based on an internal zone. This line would be lower for a space with external loads. The small solid line in the upper right hand corner of each graph represents the current requirement for DCV in the AB970 standards.

Table 11 presents the simulation results in tabular format. For each climate zone, there are 16 columns. The first three columns present the cooling energy savings from DCV in kWh/ft^2 for each of the three occupant densities. The next three columns present the heating savings in therms/ft^2. The next three columns present the present value of the energy cost savings in $/$ft^2$. The next two groups of three columns present the life cycle cost thresholds expressed in ft^2 of space and total HVAC system outdoor air, respectively. The final column presents the climate construction weights from the AB970 Impact Analysis Report.

In order to review the cost effectiveness implications of the figures, one example from Figure 3 is examined. In climate zone 6 (CZ6) and at a density of 14 ft^2/person, as long as an economizer is already in place (prescriptive requirement and modeling assumption), the DCV is cost effective in all spaces larger than about 600 ft^2. However, the economizer is required only according to §144(e) and only above approximately 1,800 ft^2. Therefore, because benefiting from DCV requires having an economizer in place, the recommended standard needs to be relaxed to requiring DCV at the point that an economizer is required.

All of the climate zones are cost effective at zone sizes below the approximate economizer cutoff for 14 and 20 ft^2/person densities. Similarly, 14 of the climate zones and the results of the weighted average climate zone are cost effective at 40 ft^2/person. Two climate zones have DCV breakpoints very near the approximate economizer cutoff and are at the margin of cost effectiveness.

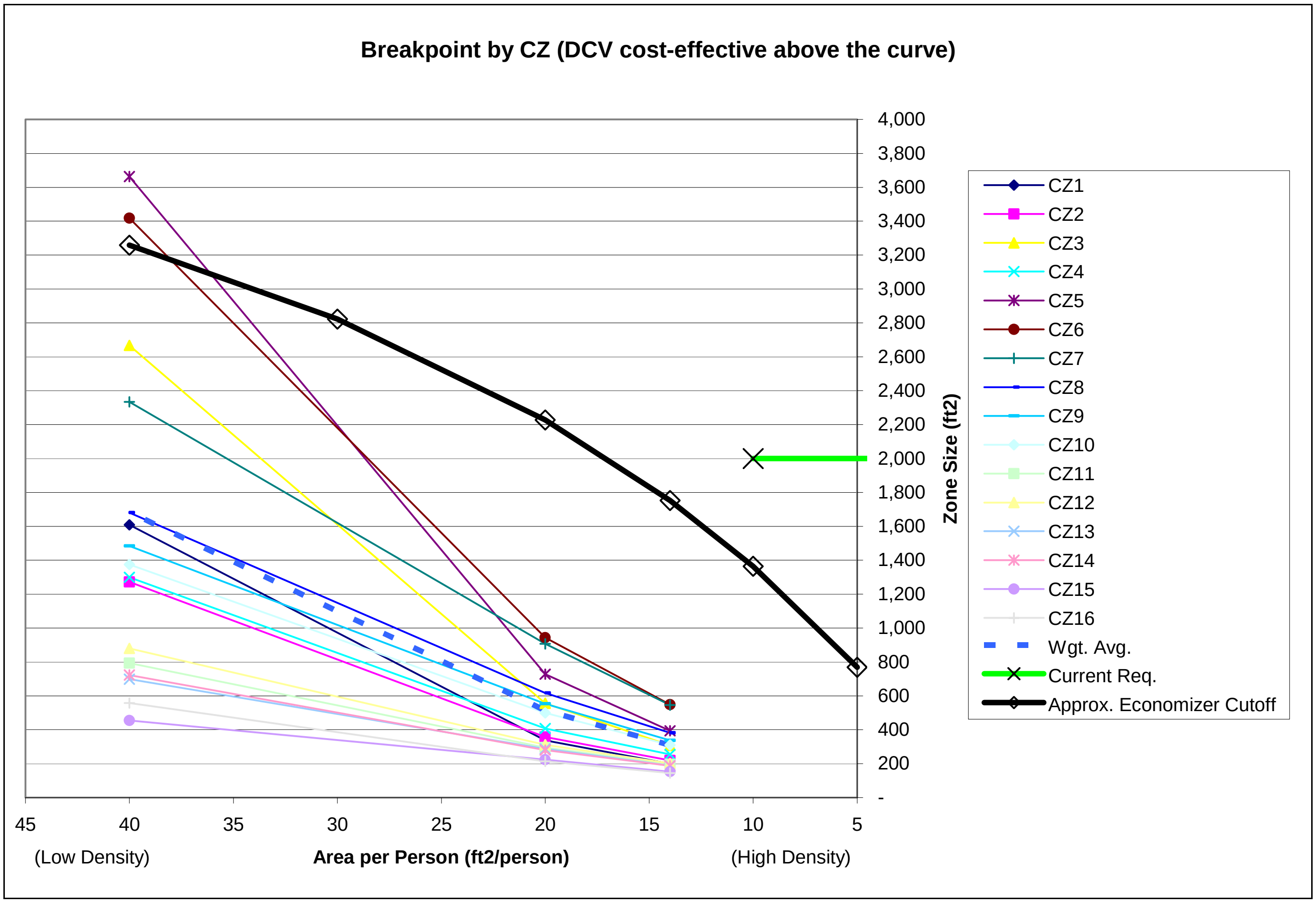

Figure 3 - Cost Effective Breakpoints and Proposed Requirements as a Function of Zone Size and Occupant Density

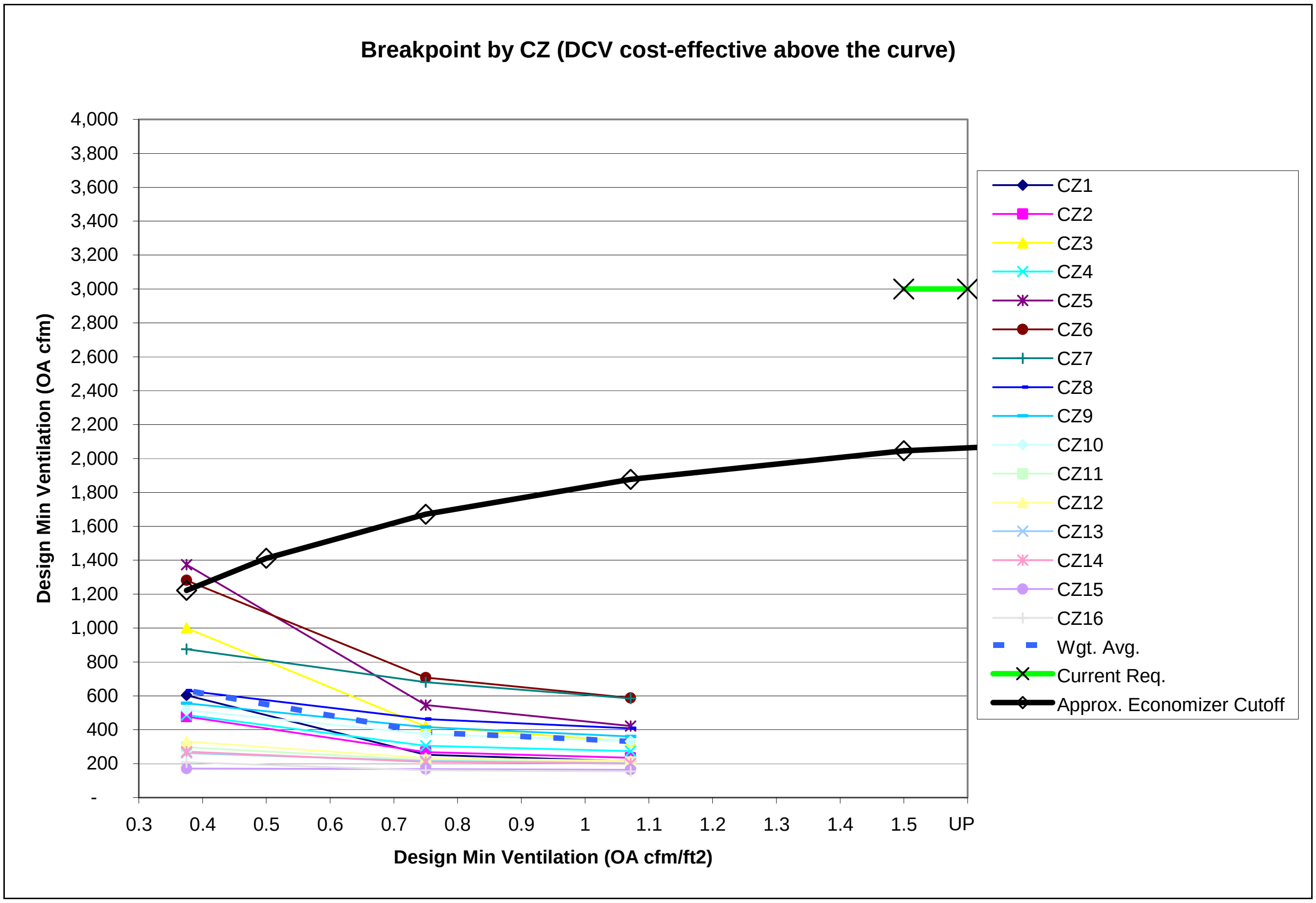

Figure 4 - Cost Effective Breakpoints and Proposed Requirements as a Function of HVAC System Design OSA and Design OSA Per Area of Space

Table 11 - Simulation Results in Tabular Format

	Savings KWH/ft2			Savings therm/ft2			Savings$/ft2			Breakpoint (ft2)			Breakpoint (osa)			Weights
CZ	14	20	40	14	20	40	14	20	40	14	20	40	1.0714	0.75	0.375	
CZ1	0.00	(0.01)	(0.01)	0.40	0.24	0.05	$ 2.89	$ 1.71	$ 0.36	199	337	1,609	213	252	603	0.3%
CZ2	0.27	0.16	0.06	0.31	0.19	0.05	$ 2.63	$ 1.61	$ 0.45	219	357	1,272	234	268	477	7.0%
CZ3	0.16	0.10	0.05	0.42	0.23	0.04	$ 3.28	$ 1.82	$ 0.32	175	317	1,782	188	237	668	15.9%
CZ4	0.37	0.26	0.14	0.24	0.15	0.04	$ 2.26	$ 1.41	$ 0.44	255	408	1,299	273	306	487	7.1%
CZ5	0.05	0.02	0.01	0.19	0.11	0.02	$ 1.46	$ 0.79	$ 0.16	394	727	3,663	422	546	1,374	1.9%
CZ6	0.18	0.13	0.07	0.11	0.06	0.01	$ 1.05	$ 0.61	$ 0.17	548	944	3,418	587	708	1,282	6.0%
CZ7	0.32	0.22	0.13	0.09	0.05	0.01	$ 1.05	$ 0.63	$ 0.25	545	907	2,335	584	680	875	7.5%
CZ8	0.51	0.36	0.20	0.11	0.06	0.01	$ 1.51	$ 0.93	$ 0.34	382	617	1,680	409	462	630	8.8%
CZ9	0.64	0.44	0.23	0.12	0.06	0.01	$ 1.71	$ 1.04	$ 0.39	336	553	1,484	360	415	557	10.4%
CZ10	0.69	0.47	0.23	0.13	0.07	0.02	$ 1.86	$ 1.15	$ 0.42	310	500	1,374	332	375	515	8.4%
CZ11	0.65	0.44	0.21	0.28	0.19	0.06	$ 2.93	$ 1.95	$ 0.73	196	294	792	210	221	297	1.4%
CZ12	0.54	0.37	0.18	0.29	0.19	0.06	$ 2.85	$ 1.85	$ 0.65	202	311	880	216	233	330	14.5%
CZ13	1.03	0.72	0.36	0.23	0.14	0.05	$ 3.05	$ 2.00	$ 0.82	188	287	699	202	215	262	6.0%
CZ14	0.86	0.59	0.29	0.26	0.17	0.06	$ 3.08	$ 2.05	$ 0.80	187	280	723	200	210	271	2.4%
CZ15	2.40	1.69	0.87	0.07	0.04	0.01	$ 3.77	$ 2.57	$ 1.26	153	224	455	164	168	170	2.0%
CZ16	0.16	0.09	0.03	0.52	0.35	0.14	$ 3.98	$ 2.68	$ 1.03	144	214	557	155	161	209	0.5%
Wgt. Avg.										289	476	1,545	309	357	579	

Recommendations

Proposed Standards Language

121(c)3 Required Demand Control Ventilation. HVAC single zone systems shall have Demand-Control Ventilation systems complying with 121 (c) 4 provided:

A. They have an outdoor air economizer; and

B. They primarily serve a single room with a design occupant density greater than or equal to 25 people per 1,000 ft^2 (40 ft^2/person), or the room's occupancy type per Chapter 10 of the UBC is "Assembly Areas," "Concentrated Use (without fixed seats)," "Auction Rooms," "Assembly Areas, Less-Concentrated Use," or "Classrooms."

121(c)4 Demand-Control Ventilation systems shall:

A. Be a CO_2 sensor that has an accuracy of no less than 75 ppm, that is factory calibrated or calibrated at start-up, and that requires calibration no more frequently than once every five years. The sensor shall be located in the room between 1 ft and 6 ft above the floor;

B. Reduce outdoor air ventilation rates below the design outdoor air ventilation rate when the number of occupants in the space is below the design occupancy. The controls shall be set to provide no less than 15 cfm per person of outdoor air as calculated by Equation 1-X;

C. Maintain outdoor air ventilation rates no less than the rate listed in Table 1-F times the conditioned floor area, regardless of occupancy, when the system is operating during hours of expected occupancy; and

D. Supply the design outdoor air ventilation rate when the sensor fails or provides a reading out of normal range.

Equation 1-X

$$R_p = \frac{8{,}400 \times m}{C_R - C_{OA}}$$

where,

R_p = The rate of outdoor air per person (cfm/person)

m = The metabolic rate (1 met = 58.2 W/m^2). The default metabolic rate is 1.2 mets.

C_{OA} = The outdoor air CO_2 concentration (ppm). The default outdoor air CO_2 concentration is 400 ppm.

C_R = The room CO_2 concentration (ppm) measured by the sensor.

Proposed ACM Language

The proposed ACM language is yet to be developed. It is recommended that systems with complying DCV controls be modeled with half of the design minimum outdoor air set point down to a floor of the cfm/ft^2 rates listed in Table 1-F. The same assumptions would be used in the base case building for systems that would be required to have DCV controls per the proposed Section §121(c)3.

Bibliography and Other Research

AB 970 Impact Analysis.

Eley Associates and NBI, Utility Cost Forecasts, Years 2005 through 2035. February 19, 2002.

Steven J. Emmerich and Andrew K. Persily. State-of-the-Art Review of CO_2 Demand Controlled Ventilation Technology and Application. NISTIR 6729, March 2001.

OSHA Proposed Rule On Workplace Indoor Air Quality, 1994.

C.D. Keeling, T.P. Whorf. Scripps Institution Of Oceanography, University of California, La Jolla, CA.

M.M Mendell. "Non Specific Symptoms In Office Workers: A Review and Summary Of the Epidemiologic Literature," Indoor Air 1993.

Schell, M.B. and D. Int-Hout. "Demand Control Ventilation Using CO_2." ASHRAE Journal. February 2001.

O.A. Seppanen, W.J. Fisk, M.J. Mendell. "Association of Ventilation Rates and CO_2 Concentrations with Health and Other Responses in Commercial and Institutional Buildings," Indoor Air 1999.

Schell, M.B., S.C. Turner, and R.O. Shim. "Application of CO_2-Based Demand-Controlled Ventilation Using ASHRAE Standard 62: Optimizing Energy Use and Ventilation." ASHRAE Transactions 104: 1213-1225. 1998.

ASHRAE. ASHRAE/ANSI Standard 62-2001, Ventilation For Acceptable Indoor Air Quality.

ASHRAE. Users Manual for ASHRAE/ANSI Standard 90.1, 1999.

International Code Council. Commentary To The International Mechanical Code 2000, Section 403.3.

Carrier Corporation. "Demand Control System Design," 2001.

Construction Quality – Walls

Overview

Standard practice in the residential construction industry results in numerous construction defects contributing to increased energy usage and oversized cooling systems. There are many opportunities to improve the construction quality of residential building envelopes by paying more attention to the way insulation, framing, and the building's air barrier are installed. Opportunities also exist to improve the current protocols in the standards that are used for field verification, including use of improved diagnostic tools. This analysis focuses on exterior walls in low-rise residential buildings. Other low-rise residential construction quality issues will be discussed in a subsequent paper.

Description

The current construction industry focus on streamlining the construction process, with the resulting inattention to details, results in a finished product that is not consistent with the design intent. Oak Ridge National Laboratory's Building Technology Center has been leading efforts in hot-box testing of various wall assemblies to quantify the effects of insulation installation defects. The Oak Ridge testing has attempted to quantify the degradation of various "defective" wall constructions relative to its nominal rating. Installation defects occur due to: shoddy installation, voids, rounded shoulders at exterior cavity corners, batt compression due to wiring, plumbing, and electrical boxes, and insulation stuffed into narrow cavities. Results presented in *Energy Design Update* report that the "clear wall" performance of a 2x6, R-19 wall, 24 in. o.c. wall is degraded after accounting for the "real world" impacts from an average of R-16.5 to R-11.0[5]. Although the Oak Ridge data represents rigorous testing under carefully controlled conditions, it is difficult to extrapolate whole house performance from test results on the 8 ft by 8 ft tested wall section.

Phase II of the California Energy Commission's Residential Construction Quality Assessment Project (RCQA) included work tasks to develop and implement a field wall insulation inspection methodology. The goal of the RCQA wall insulation inspection method is to accurately quantify actual wall performance by calculating an overall exterior wall "UA" for a sample of new California production homes. "Real" wall thermal performance is degraded from ideal performance by two factors: *increased framing* in the wall cavity and *insulation installation defects*, including compressed insulation due to wiring and plumbing, shoddy installation, voids, rounded shoulders at exterior cavity corners, and insulation stuffed into narrow cavities. Enermodal Engineering and Chitwood Energy Management[6] completed a study on framing factors that pursues the quality of insulation installations.

Current Title 24 modeling rules assume favorable wall performance both in terms of a low framing factor and cavity R-values. For example, a typical 2x4, 16 in. o.c. wall with R-13 cavity insulation assumes a non-degraded R-13 in the cavity and a framing factor of only 15%. Recent research completed by Enermodal Engineering and Chitwood Energy Management indicate typical California wall framing factors of 26%, based on a sample of single-family detached houses surveyed statewide. Higher framing factors degrade overall wall U-value, particularly for wall systems without exterior rigid insulation. The goal of the RCQA insulation inspection procedure was to combine a "real" framing factor assumption with a representative cavity R-value for all exterior wall surface area.

This study surveys 10 industry standard buildings to determine how the effective insulation R-values differ from the labeled R-values, after the installation defects and the observed framing factors are considered.

5 "*How Thermal Shorts and Insulation Flaws can Degrade an R-19 Stud Wall to a Measly R-11*". Energy Design Update. Cutter Information Corporation. September 1999.

6 *Characterization of Framing Factor for Low-Rise Residential Building Envelopes in California*, 2001.

Benefits

By changing the current calculations to represent standard practices and offering a credit to homebuilders for HERS-verified "quality" work, homebuilders have an incentive to improving the quality and integrity of the building envelope. An improved building envelope leads to improved building comfort, increased customer satisfaction, possible reduced use of framing materials, reduced cooling system sizing (once HVAC contractors gain confidence that building envelope performance is reliable), and reduced potential for construction litigation.

Environmental Impact

The overall environmental impact of pursuing a quality assurance construction initiative is highly favorable with benefits accruing from both reduced resource consumption in the construction process and reduced energy use over the envelope lifetime.

Type of Change

This initiative recommends adjusting the U-value calculation methodology currently used in the standards to reflect the industry standard framing factors identified by the Enermodal Engineering and Chitwood Energy Management study and the insulation installation defects identified in this study in order to account for the degradation of performance due to suboptimal construction practices. Revising exterior wall U-values based on "real world" wall framing assumptions and cavity insulation performance is a fairly simple process involving the parallel path calculation methodology. Adjusted U-values are easily incorporated in the modeling approach for both "prescriptive" and "performance" wall systems.

In conjunction with degraded standard wall performance, a credit is proposed for third-party documented "improved" insulation installation quality. This *budget neutral* approach flexibly allows the industry time to achieve the desired higher installation quality level, while providing a credit to those builders currently installing quality wall insulation systems.

Measure Availability and Cost

There are no product-based limitations in the availability of enhancing residential construction quality. The limitations lie in ability of the measure to change the status quo of the construction industry. Without education of the building community, residential construction quality compliance credits may not be wholeheartedly embraced. For comparison, the initial response to the tight duct compliance credit introduced in 1999 was weak. Insulation installers, among the lowest paid trades in the construction industry, must be better trained and compensated to competently complete their work. In the RCQA project, there were instances where builders were aggressively pursuing higher quality wall insulation installation standards from their insulation subcontractor. Wide adoption of the improved construction credit will depend on communicating improved installation procedures and helping the building community understand the value (compliance benefit, improved construction quality, market differentiation, and reduced litigation potential) of the approach.

The availability of proper inspection for the compliance credit will involve the training of HERS raters to perform the inspection task. A detailed inspection requires an understanding of *where to look* and *what to look for*. Additional HERS rater training with a field training component will be needed to achieve the required level of competence. Given the short time window available for wall insulation inspections, a sampling procedure is recommended.

Small additional costs from increased labor and inspection costs are associated with this initiative. The additional initial costs may be offset by cost reductions arising from HVAC equipment "right-sizing". Additionally, long term cost savings will result from improved building operation.

Useful Life, Persistence and Maintenance

This approach provides an avenue for securing Title 24 credits for a quality wall insulation job. Since wall insulation has lifetime performance implications for the house, it is important that industry standard work be differentiated from quality installations. A quality insulation installation will provide consistent and persistent savings over the lifetime of the building and has no maintenance requirements. Equally as important, it will give the HVAC industry greater confidence in the thermal integrity of the building envelope, leading to future equipment downsizing. Savings from smaller equipment would persist for the life of that equipment.

Performance Verification

Performance verification is a key element of this initiative. Performance verification provides the assurance to the builder and HVAC contractor that the installed wall system meets the design intent. The HERS rater must be provided with the proper training and the proper evaluation methodology to complete an accurate assessment of building envelope integrity. A detailed HERS rater checklist or scorecard needs to be developed. A first draft, based on the wall insulation checklist on the CEC's web site[7] is included in Appendix C.

Analysis Tools

MICROPAS/CALRES can be used to evaluate the energy savings impact of this initiative.

Relationship to Other Measures

Incorporation of this residential construction quality initiative in the standards would result in the derating of existing building envelope parameters to reflect "industry standard" practices. This derating would increase the cost effectiveness of all other space conditioning efficiency measures, with the magnitude of the impact depending upon the climate zone and building design.

Methodology

Surveying homes under construction provided opportunity to study construction quality issues in walls. The survey is conducted after the insulation was installed in the walls, but before the walls are covered with the interior finish. The wall survey procedure begins at the front door of the house and works around the perimeter of the house in a systematic fashion. For each new exterior wall section, the user enters the following data into the spreadsheet:

- Nominal wall construction for that wall section (e.g. 2x4, 16 in. o.c., R-13 cavity, R-4 exterior).
- Gross wall dimensions (length x height).
- Area of any window or doors.
- Defect characterization (area and R-value[8]).

Multiple defects are typically identified for each wall section. Void areas are calculated at zero cavity R-value. Other insulation defects require determination of an "average % compression" (the relationship to a resulting *R cavity* is described below) for the defect and an associated defect area. The UA calculation follows a standard parallel path calculation as shown in Figure 5. Each defect area contributes to the overall UA for that wall section. If there are no observed defects for part (or all) of the wall section, the U-value for that area is not degraded[9]. Each wall section is represented by a summation of "subareas", as shown in the equation below, which total the net wall area for that section. The parallel path, U-value calculation methodology is then used to determine overall wall UA.

---

7 See www.energy.ca.gov/efficiency/qualityhomes/insulation_checklist.pdf.

8 For voids, the defect has a "0" R-value; compression R-value is based on the Figure 1 regression curve.

9 Beyond adjusting for the 26.1% framing factor.

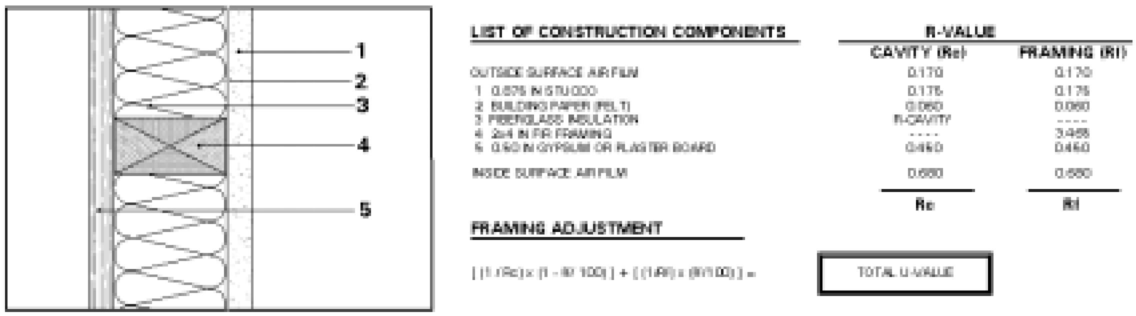

Figure 5 – Parallel Path U-value Calculation Methodology

Wall Section UA = $\sum_{i=1}^{n} U_1A_1 + U_2A_2 + ... + U_iA_i$

where,

U_i = parallel path calculated U-value based on cavity R-value and wall construction characteristics.

A_i = defect area.

By systematically working through the house, all exterior wall areas are surveyed and characterized in terms of nominally performing wall area and defect wall area.

As fiberglass insulation is compressed, the nominal R-value decreases due primarily to a reduction in the amount of air trapped between the individual fibers. Table G-5 of the *Residential Manual for Compliance with the 1998 Energy Efficiency Standards* presents manufacturer's data on the impact of compression on nominal R-value. The Table G-5 data points were plotted and a second order regression was fitted to the data. The regression relationship, shown in Figure 6, was incorporated into an Excel-based wall insulation takeoff form developed for the RCQA Project.

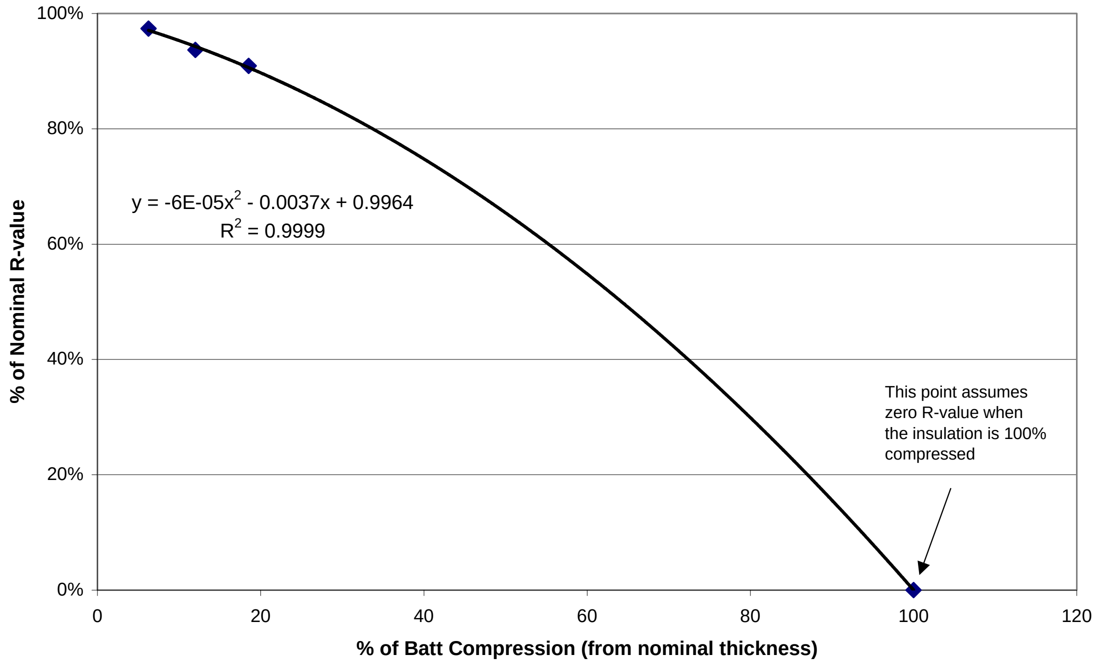

Figure 6 –Cavity R-value Degradation due to Fiberglass Batt Compression

Results

A total of 10 sites are inspected using this procedure. All 10 sites are production homes in Northern California ranging in size from 1,330 to 2,100 ft^2. Five of the sites could be classified as "industry standard" insulation jobs and five were "high quality" jobs[10]. Nine of the 10 sites were batt insulated 2x4 walls, and the tenth was a spray-applied cellulose insulated wall. "UAs" were calculated under the following assumptions:

- *Current Title 24* (no insulation defects and 15% framing factor for 2x4, 16 in. o.c.).
- *Framing factor adjusted* (no defects and 26.1% framing factor).
- *Defect and framing factor adjusted* (observed defects and 26.1% framing factor).

The impact of adjusting the framing factor to the 26.1% Enermodal average results in a fairly uniform 10% to 13% increase in overall wall average U-value for the 10 houses relative to the current Title 24 assumption. The small variation among sites is due to the fact that framing factor has a larger impact on walls without exterior insulation (e.g. garage walls).

Table 12 summarizes results from the 10 sites looking at the impact of insulation installation defects on the average wall U-value. For the "industry standard" cases, accounting for observed insulation defects increases the average U value by 20% (from 0.102 to 0.122 Btu/hr-ft^2-°F) over the framing factor adjusted U-value. For the "high quality" batt insulation cases, accounting for the defects increases the average U by only 3%, from 0.103 to 0.106. For Case J, with spray-applied cellulose insulated walls, no installation defects are found[11].

---

10 The distinction is not only based on the quality of the insulation work, but what the installers were getting paid to do the work. For the "high quality" jobs, the insulation contractors were getting paid 27% 30% more to do the job correctly.

11 The spray applied cellulose completely filled the wall cavity and was flush with the studs providing direct contact between the air barrier and the insulation.

Table 12 – Average Wall U-Values (Btu/hr-ft^2-°F)

House	Nominal Wall Description	Framing Factor Adjusted	Defect + Framing Factor Adjusted
Industry Standard Wall Insulation			
A	2x4, 16” o.c., R-15 cavity (batt)	0.096	0.122
B	2x4, 16” o.c., R-13 cavity (batt)	0.103	0.126
C	2x4, 16” o.c., R-13 cavity (batt)	0.103	0.128
D	2x4, 16” o.c., R-13 cavity (batt)	0.103	0.122
E	2x4, 16” o.c., R-13 cavity (batt)	0.103	0.110
	Average	**0.102**	**0.122**
High Quality Wall Insulation			
F	2x4, 16” o.c., R-13 cavity (batt)	0.103	0.108
G	2x4, 16” o.c., R-13 cavity (batt)	0.103	0.105
H	2x4, 16” o.c., R-13 cavity (batt)	0.103	0.107
I	2x4, 16” o.c., R-13 cavity (batt)	0.103	0.1034
J	2x4, 16” o.c., R-13 cavity (blown)	0.103	0.103
	Average (of all batt houses: F-I)	**0.103**	**0.106**

The final step involves revisiting the parallel path calculation (shown in Figure 5) to determine the overall cavity R-value necessary to generate the “defect + framing factor adjusted” U-values found in the survey. Table 13 summarizes the effective cavity R-values for each case, and the “% of nominal”. On average, the industry standard cases are found to have an effective cavity R-value equal to 69% of nominal. “High quality” batt insulated walls are found to achieve 94% of nominal rating.

Table 13 – Average Effective Cavity R-Values

House	Nominal Wall Description	Effective Cavity R-values	% of Nominal
Industry Standard Wall Insulation			
A	2x4, 16” o.c., R-15 cavity (batt)	9.0	60%
B	2x4, 16” o.c., R-13 cavity (batt)	8.5	65%
C	2x4, 16” o.c., R-13 cavity (batt)	8.2	63%
D	2x4, 16” o.c., R-13 cavity (batt)	9.0	69%
E	2x4, 16” o.c., R-13 cavity (batt)	11.2	86%
	Average		**69%**
High Quality Wall Insulation			
F	2x4, 16” o.c., R-13 cavity (batt)	11.7	90%
G	2x4, 16” o.c., R-13 cavity (batt)	12.4	95%
H	2x4, 16” o.c., R-13 cavity (batt)	11.8	91%
I	2x4, 16” o.c., R-13 cavity (batt)	12.9	99%
J	2x4, 16” o.c., R-13 cavity (blown)	13.0	100%
	Average (of all batt houses: F-I)		**94%**

Recommendations

Based on these results, it is proposed that standard cavity R-values for fiberglass insulated walls be adjusted to reflect industry standard installation quality. Modifying nominal cavity R-values for fiberglass batts by a 0.69 factor in both the “performance” and “prescriptive” wall assemblies is recommended. The measure thereby remains neutral. A credit should be offered for HERS-verified “quality” wall insulation work and for spray-applied cellulose walls. The quality fiberglass batt insulated wall would have an adjustment factor equal to 0.94. Spray-applied cellulose is proposed to have no cavity degradation. Composite R-values for wall systems using rigid insulation in addition to cavity insulation would need to be re-calculated, taking into account the above adjustments to the cavity insulation.

As part of the HERS verification process, an inspection checklist must be developed for field inspection (see Appendix C). Due to the difficulty in inspecting exposed wall insulation[12], a sampling procedure is strongly recommended.

Proposed Standards Language

These recommendations will not alter the current standards language; however, the U-factor criteria will likely change as a result of the revised calculation method. A separate analysis initiative is conducting a life cycle cost analysis to determine those revised U-factors.

Proposed ACM Language

Specific procedures for calculating U-factors will be developed, based on the recommendations. The tables of default U-factors will be revised to reflect the new calculation method.

Bibliography and Other Research

California Energy Commission. Residential Manual for Compliance with the 1998 Energy Efficiency Standards for Low-Rise Residential Buildings. 1999. Table G-5 on page G-28 presents R-values for compressed fiberglass batt insulation.

Christian, J. et al. *The Whole Wall Thermal Performance Calculator – On the Net*. Proceedings, Thermal Performance of the Exterior Envelopes of Buildings VII. Atlanta, GA. 1998. Describes the methodology and results from hot box testing of wall assemblies at Oak Ridge National Laboratory.

Davis Energy Group, Inc. *Residential Construction Quality Assessment Project: Phase II Final Report*. 2002. This report, still awaiting final CEC approval, describes the wall insulation inspection methodology and results used to quantify wall performance in this study.

Energy Design Update, "*How Thermal Shorts and Insulation Flaws can Degrade an R-19 Stud Wall to a Measly R-11*". Cutter Information Corporation. September 1999.

Enermodal Engineering and Chitwood Energy Management. *Characterization of Framing Factor for Low-Rise Residential Building Envelopes in California*. 2001. This report describes methodology and results used in characterizing framing factors for new California homes.

[12] Wall insulation is often exposed for less than a day before drywall installation commences.

Water Heating Distribution Systems

Overview

The last major changes to the Title 24 residential water heating standards were adopted in 1992, and included the following improvements:

- Substitution of energy factor for seasonal efficiency and standby loss as a water heater performance descriptor (required by NAECA), and the institution of a water heater blanket requirement.
- Introduction of a modifier of water heater performance as a function of load ("Load Dependent Energy Factor").
- Replacement of a fixed energy budget based on 50 gallons/day with a floor area-based budget developed from California hot water use data.
- Development of an engineering basis for distribution system energy loss and distribution losses (the HWSIM software).
- Development of distribution system multipliers based on HWSIM that were published in the ACM manual and account for pipe insulation, point-of-use water heaters, parallel piping, and recirculation systems.

For the 2005 standards, the analysis team has revisited the distribution system multipliers for single-family homes and recommends a revised methodology. The results of the analysis show:

- Baseline distribution losses are sensitive to floor area and number of stories,
- The modeling methodology should be modified to recognize this relationship, and
- The distribution system multipliers should be updated.

At present, a conventional water heating distribution system is assumed to be the standard design, e.g., the basis of the water heating energy budget. However, the cost effectiveness of a parallel piping system is being evaluated, with the possibility of this system becoming the basis of the water heating budget, e.g., parallel piping would be a prescriptive requirement.

Benefits

The major benefit of modifying the ACM modeling methodology would be more accurate calculation of distribution losses and characterization of DHW energy use.

If parallel piping becomes a prescriptive requirement, the life-cycle cost of water heating systems would be reduced.

Environmental Impact

None.

Type of Change

This proposal would change the modeling methodology and distribution system multipliers in the ACM manual.

If parallel piping becomes the standard design, the prescriptive water heating requirements would also change.

Methodology

Current Alternative Calculation Method (ACM)

A "standard" distribution system represents the copper "main and branch" piping approach used in most new California single-family housing. The current Standard Recovery Load[13] includes a floor area dependent fixture end use with a fixed 22% distribution loss. The distribution system multiplier (DSM) is used to adjust the floor area dependent Standard Recovery Load. Table 14 lists the distribution system multipliers specified in the 2001 ACM manual. Measures with distribution system multipliers less than 1.00 reduce the recovery load, while DSMs greater than 1.00 increase the recovery load. The values listed in Table 14 apply to all distribution systems and are independent of house size or number of stories. Current distribution system multipliers are largely based on the 1,384-ft^2 prototype used for standards development in the early 90's. The two goals of this analysis are to: 1) explore distribution loss sensitivity to floor area and number of stories, and 2) update the distribution system multipliers.

Table 14 – Current ACM Distribution System Multipliers (DSM)

Distribution System Type	Single Family DSM
Standard	1.00
Point of Use (POU)*	0.82
Hot Water Recovery *	0.82
Pipe Insulation	0.92
Parallel Piping	0.86
Recirculation (no control)	1.52
Recirculation + timer control	1.28
Recirculation + temperature control	1.05
Recirculation + demand control	0.98
Recirculation + timer/temperature	0.96
Recirculation + demand/hot water recovery	0.80
Recirculation + demand/pipe insulation	0.90

*POU and hot water recovery systems assume no distribution losses[14].

Evaluation Process

The basic evaluation process is as follows:

- Select representative one- and two-story prototype buildings.
- Lay out conventional "main and branch" piping configuration for all fixtures in each prototype.
- Develop a weekly profile of fixture draws that is consistent with the Standard Recovery Load assumptions currently used in the 2001 ACM manual.
- Use HWSIM to calculate annual distribution loss and proposed distribution system multipliers for non-recirculation measures.
- Use external calculations (non-HWSIM) to analyze recirculation systems.
- Develop a new procedure based on the above.

The HWSIM distribution loss model was developed for the 1992 water heating standards revisions work (DEG, 1991). The 1991 report[15] documents the research foundation for the current water heating methodology.

---

13 Recovery load is defined as the sum of fixture end use and distribution losses. See Table 6-5 on page 6-19 of the CEC's Residential Manual for Compliance with the 1998 Energy Efficiency Standards (for Low-Rise Residential Buildings). P400-98-002. 1999.

14 The 0.82 multiplier corresponds to a fixed 22% distribution loss, independent of load and floor area.

HWSIM is the most detailed hot water distribution loss model currently available. An alternative distribution system model is currently under development at Oak Ridge National Laboratory under a PIER contract, but is not available in time for this study.

Distribution Loss Sensitivity to Floor Area and Number of Stories

Three new single-family production homes currently being built in California are selected for modeling. The houses are a 2,010-ft^2 single-story, a 3,080-ft^2 single-story, and a 2,811-ft^2 two-story. In addition, two smaller units from the multi-family analyses are treated as single-family attached housing. These two units (960 ft^2 and 1,200 ft^2) represent the lower end of the floor area range. The 1,384-ft^2 and 1,997-ft^2 units previously evaluated in the 1991 CEC study are also revisited. Finally, the results from prior analysis of a 1,408-ft^2 two-story townhouse[16] are used to complete the range of cases.

The floor area of each plan defines an annual Standard Recovery Load, which is converted to a daily DHW usage based on the ACM's assumption of a 135°F hot water temperature and a 65°F average cold water inlet temperature. A series of draws for HWSIM to arrive at a daily average recovery load equal to the calculated daily Standard Recovery Load is then developed. Table 15 summarizes hot water usage assumptions for each fixture and Table 16 contains more detail on draw patterns and typical draw schedules. The volumes and assumed use temperatures were originally developed in the 1991 CEC work, with the exception of dishwasher and clothes washer use which are modified to reflect more efficient appliances on the market today. The results of this analysis are below in the results section.

Table 15 – Summary of DHW Use Quantities

Use Point	Volume (gals)	Assumed Use Temperature (°F)	Gallons of 135°F Water per Draw
Kitchen – 1 gal draw	1.0	105	0.57
Kitchen – 3 gal draw	3.0	105	1.71
Lavatory	0.7	105	0.40
Shower – 10 gal	10.0	105	5.71
Shower – 20 gal	20.0	105	11.43
Dishwasher	10.8	135	10.80
Clothes washer*	9.1	135	9.10
Regular bath	35.0	105	20.00
Whirlpool bath	50.0	105	28.57
* Assumes a mix of hot/warm/cold cycles; based on 20% horizontal axis penetration.			

Distribution System Multipliers Updates

Note: Hot water recovery systems are not re-evaluated, because they are no longer commercially available.

Pipe Insulation

R-4 pipe insulation is evaluated for all distribution piping and "kitchen only[17]" piping. These measures are examined to determine distribution system multipliers, as well to assess whether pipe insulation is cost effective and should become a prescriptive or mandatory measure.[18]

Parallel Piping

[15] Davis Energy Group, Inc., *California Residential Water Heating Standards – Volumes I & II*. 1991. See Volume II, Section III, Appendices A, E, and F for more detailed information on HWSIM.

[16] Davis Energy Group, Inc., *Parallel Piping Studies*, 1991.

[17] "kitchen only" requires insulating all lines from the water heater to any hot water fixtures in the kitchen including the dishwasher. These fixtures are prime candidates for pipe insulation since draws are typically small although more frequent than other fixtures.

[18] The life cycle cost methodology is documented in Eley Associates, Life Cycle Cost Methodology, March 11, 2002.

Parallel piping consists of dedicated small diameter tubing (typically 3/8 in. or ½ in. cross-linked polyethylene or copper) from the water heater to each fixture. The smaller diameter line size reduces the volume of water wasted with each draw, the energy loss in the line, and the waiting time at the fixture. For this analyses, ½ in. lines are assumed to conservatively represent the performance of parallel piping systems.

The recirculation loop configurations listed in Table 14 are analyzed based on calculated R-4 insulated pipe losses from an assumed 135°F hot water temperature to a 70°F annual average loss environment temperature, and using the following concentric cylinder heat loss equation:

$$Q = 8.76x \frac{(135 - 70)}{\frac{\ln(Dio/Dpo)}{2\Pi ki} + \frac{1}{\Pi haDio}} \text{ kBtu/ft-year}$$

where,

Dio = outside diameter of insulation (ft).

Dpo = outside diameter of pipe (ft).

ki = insulation conductivity (0`.023 Btu/hr-ft-°F).

ha = air film coefficient (1.65 Btu/hr-ft^2-°F).

The 3,080 ft^2 one-story prototype is selected as the one most likely to have a recirculation system. The premise in determining the energy impact of recirculation systems is that the "standard" main and branch distribution loss is fully replaced by the calculated recirculation distribution loss, and assumes that piping losses downstream of the recirculation loop are essentially zero[19].

Recirculation

The options reviewed in modeling the recirculation options include:

- *Continuous recirculation*: Assumes continuous pump operation for a 40-W circulator supplying 1 gpm through the loop.
- *Timer control*: Assumes the circulation pump operates 16 hours per day.
- *Temperature control*: Assumes that the loop is continually maintained between 110ºF and 135°F (117.5°F average) in response to a temperature sensor on the hot water return line.
- *Time/temperature control*: Provides temperature control (see above) for 16 hours each day.
- *Demand control*: Evaluation of this is based on information provided by Advanced Conservation Technology, Inc., manufacturer of the Hot Water D'MAND System[20]. This technology uses push-button or occupancy sensor activation of the recirculation pump. When initiated, a circulator in the hot water line sends water from the water heater to the fixture, returning cooled water in the hot line to the cold water "return" line. The pump operates for a brief interval until a temperature sensor indicates hot water has arrived at the fixture.

Calculations

For each of the distribution systems, HWSIM runs are made using commercially available natural gas storage water heaters that comply with the 2004 NAECA standards[21]. A compliant 40-gallon water heater has a 0.594 Energy Factor, a recovery efficiency of 76.3%, and an input rating of 40,170 Btu/hr. A compliant 50-gallon water heater has a 0.575 Energy Factor, a recovery efficiency of 76.5%, and an input rating of 45,810 Btu/hr. It

---

19 To insure that the distribution losses downstream of the recirculation loop are minimal, a maximum run-out length of 8 ft from the recirculation loop to each hot water fixture should be required. This is consistent with the requirement for POU water heaters which also assume no distribution loss. Clothes washers should be exempt from this 8 ft requirement to avoid extending the recirculation loop to an appliance.

20 See more detailed description of system and operating principles at www.metlund.com.

21 The National Appliance Energy Conservation Act (NAECA) standards have been revised with the revisions scheduled to take effect January 1, 2004.

is assumed that houses under 2,000 ft^2 have a 40-gallon water heater, and that larger houses have a 50-gallon water heater.

Characterization of Loads, Draw Pattern, and Piping Configuration

Each floor area defines the SRL. Table 16 lists the number of draws at each fixture for the one-week simulation period used by HWSIM. The 2,811-ft² and 3,080-ft^2 plans both have the same SRL. Figure 7 plots a typical usage pattern for the week, as input to HWSIM. Usage patterns vary by plan as additional draws are added.

Table 17 lists piping lengths for each of the plans modeled.

Table 16 – Number of Weekly Fixture Draws by Plan

Plan	Lavatory	Kitchen	Showers	Baths	Washer	Dishwasher
960	38	35	16	1	5	4
1200	39	36	17	1	6	5
1384 / 1408	45	49	17	1	6	5
1997 / 2010	58	59	18	2	7	5
2811 / 3080	70	59	20	2	8	5

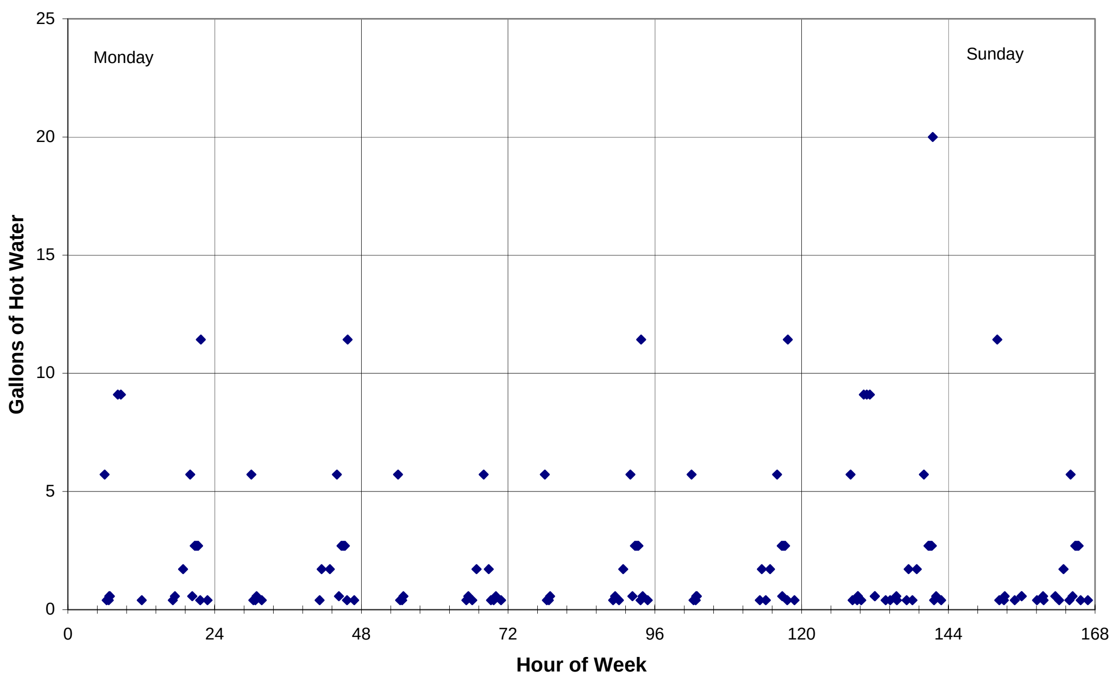

Figure 7 – Sample Hot Water Use Pattern

Table 17 – Pipe Lengths for Standard "Main/Branch" Piping Layout

		Feet of pipe		
Plan	**# of stories**	**1"**	**¾"**	**½"**
960	1	0	26	69
1384	1	0	21	58
1408	2	0	8	41
1997	2	0	26	83
2010	1	8	46	89
2811	2	6	39	131
3080	1	19	30	72

Results

Distribution Loss Sensitivity to Floor Area and Number of Stories

Table 18 summarizes the distribution losses for the standard (non-recirculation) case for each of the building prototypes. The table shows annual distribution loss (DL) in therms of gas use and as a percentage of total water heating recovery load[22].

Table 18 – Summary of HWSIM "Standard" Piping Layout Results

		Annual Distribution Loss	
Floor Area (ft^2)	**Number of Stories**	**% of Recovery Load**	**Therms**
960	1	15.2%	15.0
1200	1	17.9%	19.6
1384	1	22.6%	19.5
2010	1	24.7%	33.4
3080	1	24.0%	36.1
1408	2	7.9%	8.2
1997	2	14.0%	16.4
2811	2	18.1%	25.3

Figure 8 shows how distribution losses vary with floor area and number of stories. Larger homes typically have more fixtures further separated and therefore lose more energy in the piping system compared to a small compact house. Likewise, two-story homes benefit from shorter piping runs than a comparably sized one-story house. Figure 8 also shows some anomalies; for example, the distribution loss for the 2,010-ft^2 and 3,080-ft^2 prototypes are roughly the same. These anomalies result from variations in house size, house configuration (aspect ratio, room locations), and fixture locations.

22 Recovery load is defined as the sum of the fixture end use and the distribution losses.

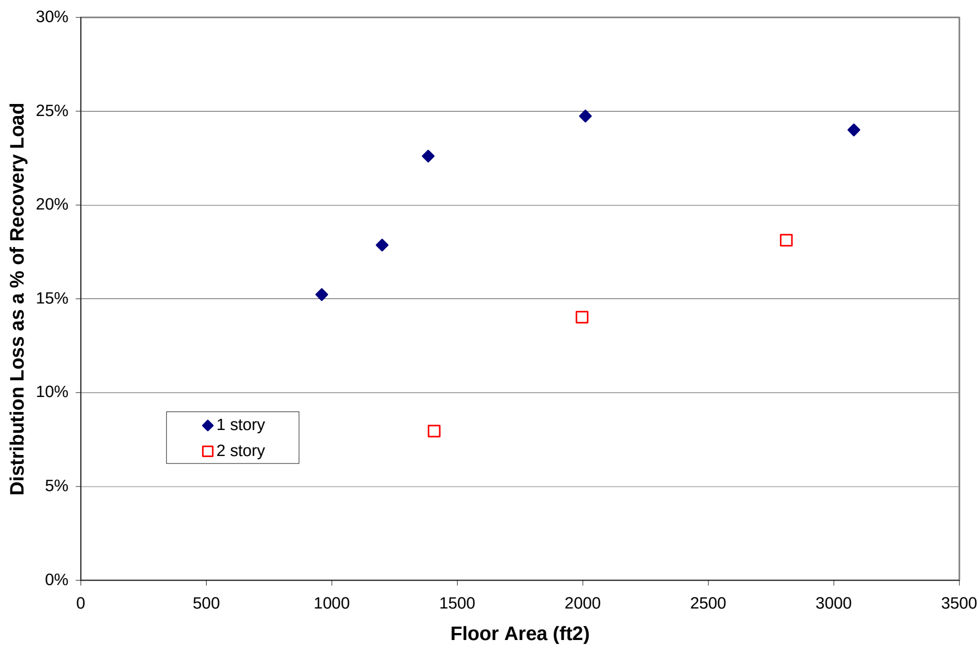

Figure 8 – HWSIM Results Summary for Standard Piping Layouts

Distribution System Multiplier Update

Pipe Insulation

Table 19 summarizes the results of HWSIM simulations for adding R-4 pipe insulation. “PV$” is the present value of the annual gas savings at the specified life cycle gas value of $13.27 per therm. If PV$ is greater than the cost, then the insulation is cost effective. Pipe insulation is cost effective for the kitchen lines of all prototypes except the 2,811-ft² house.[23] An average of the five prototypes shows the present value of the savings is more than 50% greater than the costs. Insulating all lines is not nearly as economical. The insulation is cost effective for only the 1,384-ft² prototype. For the five prototypes, R-4 pipe insulation is projected to save 21% on “kitchen-only” lines and 27% on all lines.

Table 19 – Summary of Pipe Insulation Savings and Economics

	Kitchen Lines Insulated			All Lines Insulated		
Prototype	**Therms/yr**	**PV$**	**Cost**	**Therms/yr**	**PV$**	**Cost**
960	3.6	$48	$45	3.8	$50	$115
1384	12.6	$167	$56	12.8	$170	$96
2010	7.6	$101	$80	12.2	$162	$173
2811	2.2	$29	$48	4.2	$56	$213
3080	6.3	$84	$54	9.8	$130	$210
Total		$429	$283		$568	$806
Note: Shaded areas represent cases that are not cost effective.						

[23] Costs are based on $.50 per foot for pipe insulation, $.33 per foot labor (150 feet of pipe insulated per hour at $50/ hour rate), and a 30% markup on materials and labor.

Parallel Piping

The evaluation of parallel piping occurs on three plans: the 1,384-ft², the 2,010-ft², and the 2,811-ft² prototypes. Projected savings relative to the "standard" distribution loss averaged 12% for the ½ in. configuration. Additional analysis will be completed to assess whether parallel piping is cost-effective relative to standard main and branch configurations.

Recirculation

Analysis of recirculation systems is limited to the 3,080-ft² prototype. The recirculation analyses begin by calculating an hourly loop pipe loss of 1,566 Btu/hour for the "as built" recirculation piping system.[24] Table 20 summarizes the recirculation results for the uncontrolled case, timer control, temperature control, time/temperature control, and demand control. In all cases, the "standard" distribution loss is eliminated based on the assumption that all fixtures (with the exception of the washing machine) are within 8 ft of the recirculation loop.

Table 20 – Summary of Recirculation Distribution Loss (DL) Results

Recirculation Scenario	Annual DL Therms	DL Ratio to base case	Annual Pump Energy (kWh)
Base Case	36.1	n/a	0
Uncontrolled recirculation	137.3	3.80	350
Timer (16 hours/day)	91.6	2.54	234
Temperature (110-135F)	113.2	3.14	53
Time/Temperature (16 hours)	75.5	2.09	35
Demand Control	39.8	1.10	23

The cost benefit analysis of possible control technologies for recirculation methods shows that a combined time/temperature control is cost effective. The following scenarios compare the life cycle cost (LCC) savings of adding control devices to an uncontrolled recirculation system. A simple timer control provides LCC benefits of $846, while installation costs $143. Similarly, a temperature control generates LCC benefits of $934 at a cost of $98[25]. A combined time/temperature control provides exceptional LCC benefits of $1,472 at a cost of $241. Because the service quality is not equivalent, demand control is not required at this time, although it showed the lowest distribution losses. Based on these results, recirculation control should be limited to the following options: time/temperature and demand control.

Recommendations

Distribution Loss Sensitivity to Floor Area and Number of Stories

Based on analysis results, it is recommended that single-family DHW distribution losses be based on both conditioned floor area and number of stories. This is a deviation from current ACM rules where the Standard Recovery Load incorporates a fixed 22% distribution loss. To disaggregate distribution loss from the Standard Recovery Load, altering the current relationship for Adjusted Recovery Load (ARL) in the ACM from the relationship shown in Equation A to Equation B is recommended.

Equation A (current ACM) $ARL = SRL \times DSM_{92} \times SSM$

Equation B (proposed ACM) $ARL = SEU \times SDLM \times DSM_{05} \times SSM$

where,

ARL = Adjusted recovery load.

24 Calculated using the Equation #1 heat loss relationship and the installed recirculation system piping configuration (172 feet of ¾" and 70 feet of 1" line).

25 Timer costs of $143 were conservatively based on a $60 cost for the timer, $50 labor, and 30% markup. Temperature control costs of $98 were based on $25 for the temperature control, $50 labor, and 30% markup.

SRL = Standard recovery load. This is calculated as a function of conditioned floor area (CFA) within the ranges of 1,000 ft² and 2,500 ft².

DSM_{92} = The distribution system multipliers published in the current residential ACM manual.

SSM = Solar savings multiplier. This is equal to 1.00 if no solar DHW system is installed.

SEU = Standard end use, which is equal to 82% of the SRL. With time dependent valuation (TDV), it is recommended that SEU be calculated as follows:

SEU = Gallons/Hour × ΔT × 8.33 Btu/Gallon-ºF

Hot water consumptions for each hour and the ΔT would be specified in the residential ACM manual such that 0.82 × SRL equals the SEU[26]. This provides consistency with the 1992 procedure. Also, hot water consumption varies with house size between 1,000 ft² and 2,500 ft².

SDLM = Standard distribution loss multiplier. This is the distribution loss multiplier of the standard design water heating system. This will varies with house size and number of stories as described below.

DSM_{05} = The distribution system multipliers recommended for the 2005 standards. DSM_{05} is 1.0 unless a system listed in Table 22 is used.

It is recommended that the standard distribution loss multiplier (SDLM) be dependent only on floor area and number of stories, as shown in Figure 9. This figure is a linear fit of the data from Table 18. The SDLM for a given floor area and "number of stories" would be determined by adding the calculated "distribution loss %" to 1.0. For example, a one-story 2,000-ft² house would have a distribution system multiplier of 1.28.

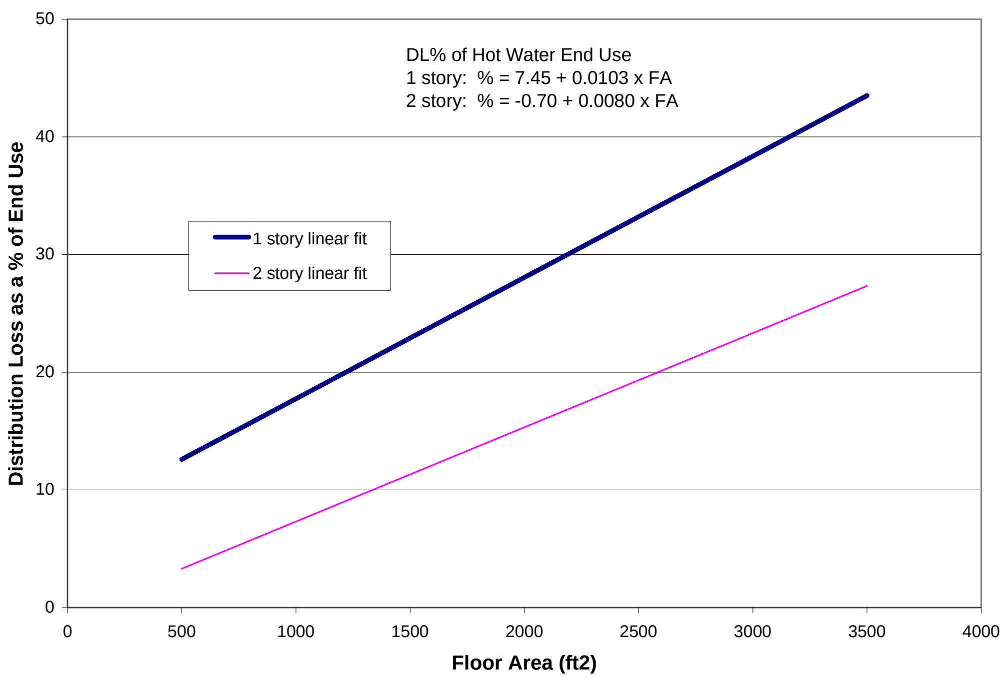

Figure 9 – Relationship of SDLM to Floor Area
Note: the 2-story curve is to be used for houses with three stories.

A key question relating to this approach is whether SDLM should be floored at 1,000 ft² and capped at 2,500 ft², which is consistent with the current approach that caps SRL at 2,500 ft². The 2,500 ft² cap is recommended, since at the current time, sufficient data are not available demonstrating increasing hot water usage (and therefore distribution losses) with house size in very large houses.

[26] This is based on the fixed 22% distribution loss included in the SRL calculation.

Table 21 summarizes the proposed standard distribution loss multipliers (SDLM) based on the linear regression lines. The values shown for both one- and two-story cases represents the distribution system multiplier variation between a 1,000-ft^2 house and a 2,500-ft^2 house, where the level is proposed to be capped. Point-of-use water heaters are assumed to eliminate all distribution loss (SDLM = 1.0) with the requirement that all use points, excluding the clothes washer, are within 8 ft of the instantaneous heater.

Table 21 – Proposed ACM Distribution System Multipliers

Distribution System Type	Single Family DSM
"Standard" one-story	1.18 – 1.33
"Standard" two-story	1.07 – 1.19
Point of Use (POU)	1.00

Revised Distribution System Multipliers

Table 22 summarizes proposed updates to the DSMs. Hot water recovery systems are no longer available on the market and should therefore be deleted. R-4 pipe insulation on "all piping" is credited with a DSM of 0.79. Pipe insulation on all lines leading from the water heater to the kitchen fixtures become a mandatory measure based on the cost-effectiveness analysis. Parallel piping (with maximum ½ in. lines to all fixtures) are credited with a DSM of 0.88.

For recirculation systems, all options are found to increase distribution loss relative to the standard main/branch distribution loss. Uncontrolled pump operation, timer control, and temperature control should be banned. Timer, temperature, and timer+temperature controls are all determined to be cost-effective using the life cycle cost methodology and the time/temperature control provides the greatest savings. Demand control is found to be the best control option with a DSM equal to 1.10.

Table 22 – Proposed ACM DSMs

Distribution System Measure	Single Family DSM
Pipe Insulation (all lines)	0.79
Pipe Insulation (kitchen lines)	Mandatory Measure
Parallel Piping	0.88
Recirculation (no control)	3.80
Recirculation + timer control	2.54
Recirculation + temperature control	3.14
Recirculation + timer/temperature	2.09
Recirculation + demand control	1.10

Mandatory Measures

- Continue current mandatory measure for R-4 pipe insulation on the first 5 ft of hot and cold water piping from storage gas water heaters.
- Minimum R-4 pipe insulation is required for non-recirculation systems on all piping from the water heater to the kitchen fixtures (kitchen sink and dishwasher).
- Pipe insulation credit applies if all remaining hot water lines are insulated to a minimum R-4.

Eligibility Requirements

Eligibility criteria are recommended for the following optional hot water distribution systems:

Point of Use Water Heaters

- Current requirements apply.

Recirculation Systems

- All recirculation systems must have minimum R-4 pipe insulation on all supply and return recirculation piping. Recirculation systems cannot take an additional credit for pipe insulation.
- The recirculation loop must be laid out to be within 8 ft of all hot water fixtures in the house (with the exception of the clothes washer).
- Approved recirculation controls include time/temperature control and demand control. Time/temperature control must have an operational timer initially set to operate the pump no more than 16 hours per day. Temperature control must have a temperature sensor installed on the return line (within 6 ft of the water heater) with a minimum 20°F deadband. Demand control systems shall have a pump (<=1/12 hp), push button(s) or occupancy sensor(s) for pump initiation, and a temperature sensor to turn off the pump when hot water arrives at the most remote fixture. Uncontrolled recirculation, timer only, and temperature only will no longer be allowed.

Parallel Piping

- Parallel piping credit requires that each hot water fixture is individually served by a line, no larger than ½ in., originating from a central manifold located no more than 8 ft from the water heater. Fixtures, such as adjacent bathroom sinks, may be "doubled up" if the fixture unit calculations in Table 6-5 of the 1997 Uniform Plumbing Code allow.
- Acceptable piping materials include copper and cross-linked polyethylene (PEX), depending on local jurisdictions.
- 3/8 in. lines are acceptable, pending local code approval, provided minimum required pressures listed in the 1997 UPC (Section 608.1) can be maintained.

Other Issues

- *Overhead plumbing for non-recirculation systems*: All plumbing located in attics with a minimum of 4 in. of blown insulation coverage on top of the piping will be allowed to claim the "all lines" pipe insulation credit, provided that, 1) piping from the water heater to the attic, and 2) piping in floor cavities or other building cavities are insulated with R-4 pipe insulation.
- *Multiple water heaters*: The ACM should calculate SEU based on the current floor area relationship. Use of multiple water heaters would require the ACM to calculate the distribution loss based on the total conditioned floor area divided by the number of water heaters.
- *Recirculation systems*: Pumping energy needs to be distributed on an hourly basis for the proposed TDV approach, based on the following distribution of pumping energy:
    - Time/temperature: uniformly distributed 6 AM to 10 PM.
    - Demand Control: Distributed proportional to the hourly DHW use profile.

Bibliography and Other Research

Personal communication with Evelyn Baskin (ORNL) regarding status of the DHW distribution model under development for Davis Energy Group's Synergistic Water Heating and Distribution Technologies PIER project.

Personal communication with Larry Acker (Advanced Conservation Technologies, Inc) to gather information on their demand control system and savings estimates.

Personal communication with two residential plumbers relating to recirculation pipe layouts and pipe insulation costs.

Davis Energy Group. *California Residential Water Heating Standards – Volumes I and II.* 1991. These reports form the basis of the current water heating methodology and are used as a reference.

Davis Energy Group. *Parallel Piping Studies.* 1991. This report evaluates parallel piping configurations relative to standard main/branch configurations.

Eley Associates. *Comparison of Water Heater Types Using Time Dependent Valuation (TDV).* 2001. This report provides an overview of how the water heating methodology can be converted to an hourly calculation methodology for implementation with TDV.

Lutz, J.D. et al. *Modeling Patterns of Hot Water Use In Households.* LBL-37805 Rev. 1996. This report is used to revisit washer and dishwasher usage assumptions.

Appendix A – Nonresidential Lighting Models

Space Types

The tables in this appendix document the assumptions and calculations used to determine the proposed lighting power densities.

Table A-1 – Auditorium
Table A-2 – Auto Repair
Table A-3 – Bank
Table A-4 – Church
Table A-5 – Classroom
Table A-6 – Clinic
Table A-7 – Convention Center
Table A-8 – Exhibition Hall
Table A-9 – Kitchen
Table A-10 – Retail
Table A-11 – Hotel
Table A-12 – Office
Table A-13 – Laundry
Table A-14 – Industrial High Bay
Table A-15 – Industrial Precision
Table A-16 – Airport Holdroom
Table A-17 – Air Ticket Counter
Table A-18 – Mail Sorting
Table A-19 – Police Hearing/Waiting
Table A-20 – Jail
Table A-21 – Senior Reading Sitting
Table A-22 – Housing Commons
Table A-23 – Civic Waiting Room

Analysis Assumptions

Area Category Table 1-N

For each space type listed in attached (revised) Table 1-N, a power density model is constructed. The method is as follows:

1. Building types were excluded from further investigation for any of the following reasons:
   a. If upon inspection, the existing models were aggressive or current and there was little opportunity for further change.
   b. If the typical spaces are high RCR spaces with low LPD values (1.0 or less) in which even lower LPD values might prevent adequate distribution of luminaires.
   c. If upon inspection, a typical design for the space does not use full size fluorescent lamps or is not a high bay space lending itself to T-5HO or pulse start MH lamps.
2. Determine an appropriate representative model space for each type. This includes selection of room length, width and height plus choice of finish palette. In general the spaces used for the 1998 models developed by CEC staff were used except as noted in the models shown in Appendix 1.
3. Determine an appropriate lighting level and distribution based on the design process identified in the IESNA Lighting Handbook, Ninth Edition and the Advanced Lighting Guidelines 2001.
4. Determine the generic design with an assignment of total illumination by percentage to each lighting system or layer.

5. Ensure that the most efficacious and efficient practical luminaires are used.
6. Determine the power density of the model design.

These models are enclosed in a set of spreadsheets with a single workbook (see Appendix 1). Critical assumptions used in these calculations:

- Calculations use mean lumens per watt and an additional overall light loss factor of 0.80. This eliminates specific ballast factor and other complications from the process and addresses lumen depreciation issues correctly.
- Calculations are based on representative products on the market today.
- Light levels are expressed in percentage of space at a task or ambient light level, plus the ability to add a third specific level.
- Calculations use the same basic models as the 1998 standards calculations, except in a few instances (as shown below and in the spreadsheets in Appendix 1).
- New Area Category models include: Civic facilities, Housing (Public and Commons Areas), Prisoner Holding Cell, Police or Fire stations, Post office and Transportation facilities (baggage-ticket-waiting).

Whole Buildings Table 1-M

For whole buildings, the following process is used:

1. Consider only spaces for which there is an existing whole building LPD and an area category LPD that has been reduced using the process above.
2. The ratio of the current area category to current building value is calculated.
3. The new area category value is divided by this ratio to determine the new building value.

A new whole building model was added for a hotel.

Table A-1 – Auditorium

Space Type	Auditorium		1998 Area LPD	2.0		**Data Used in Calculations**	
Length	60		1998 Bldg LPD	1.8			
Width	40		Ratio	1.1			
Height	20		2003 Area LPD	1.7			
Same as 1998	Yes		2003 Bldg LPD	1.5		**Lamp Types**	**MLPW**
Finishes	70/50/20	3 Light Loss Factor	0.80		1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	30	100			4	Compact Fluorescent	55
Ambient					5	Biax/T5HO	75
Other					6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	Halogen IR	Compact Fluorescent	T8/T5		9	Other	70
Luminaire	Direct	Diffuse	Indirect				
Source Code	3	4	6				
RCR	3.65						
Percent of Total	35	33	32	100		**Finishes**	**Fixture Types**
CU of Fixture	0.90	0.45	0.35			80/70/20	Direct
Note/Source	Downlight	Sconce	Cove/uplight			80/50/20	Semi-direct
						70/50/20	Direct-indirect
Calculations						70/30/20	Semi-indirect
Average FC	30					50/50/20	Indirect
Total Net Lumens	72,000					30/30/20	Diffuse
Net Lumens #1	24,480	Gross lumens #1	27,200				Directional
Net Lumens #2	23,760	Gross lumens #2	52,800				
Net Lumens #3	23,760	Gross lumens #3	67,886				
Lamp Lumens #1	34,000	Lamp watts #1	1,700				
Lamp Lumens #2	66,000	Lamp watts #2	1,200				
Lamp Lumens #3	84,857	Lamp watts #3	943				

Minimum Theoretical Watts	3,843	
Minimum Theoretical Power Density	1.61	
Recommended Value for Standard	1.70	With Chandelier Allowance

Table A-2 – Auto Repair

Space Type	Auto repair					**Data Used in Calculations**	
Length	60						
Width	40						
Height	15						
Same as 1998	Yes					**Lamp Types**	**MLPW**
Finishes	50/50/20 5	Light Loss Factor	0.80		1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	75	50			4	Compact Fluorescent	55
Ambient	30	50			5	Biax/T5HO	75
Other					6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	T8/T5	T8/T5	T8/T5		9	Other	70
Luminaire	Direct	Semi-direct	Indirect				
Source Code	6	6	6				
RCR	2.60						
Percent of Total	40	60	0	100		**Finishes**	**Fixture Types**
CU of Fixture	0.75	0.62	0.35			80/70/20	Direct
Note/Source	Lithonia EJ	Lithonia AF				80/50/20	Semi-direct
						70/50/20	Direct-indirect
						70/30/20	Semi-indirect
						50/50/20	Indirect
						30/30/20	Diffuse
							Directional

Calculations

Average FC	53		
Total Net Lumens	126,000		
Net Lumens #1	50,400	Gross lumens #1	67,200
Net Lumens #2	75,600	Gross lumens #2	121,935
Net Lumens #3	0	Gross lumens #3	0
Lamp Lumens #1	84,000	Lamp watts #1	933
Lamp Lumens #2	152,419	Lamp watts #2	1,694
Lamp Lumens #3	0	Lamp watts #3	0

Minimum Theoretical Watts	2,627
Minimum Theoretical Power Density	1.09
Recommended Value for Standard	1.10

Table A-3 – Bank

Space Type	Bank					**Data Used in Calculations**	
Length	100						
Width	80						
Height	15						
Same as 1998	Yes					**Lamp Types**	**MLPW**
Finishes	70/50/20	3 Light Loss Factor	0.80		1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	75	40			4	Compact Fluorescent	55
Ambient	30	55			5	Biax/T5HO	75
Other	100	5			6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	Halogen IR	T8/T5	T8/T5		9	Other	70
Luminaire	Direct	Direct-indirect	Direct				
Source Code	3	6	6				
RCR	1.41						
Percent of Total	5	75	20	100		**Finishes**	**Fixture Types**
CU of Fixture	0.90	0.75	0.50			80/70/20	Direct
Note/Source	Accent light	Lithonia Mirage	Task light			80/50/20	Semi-direct
						70/50/20	Direct-indirect
Calculations						70/30/20	Semi-indirect
Average FC	52					50/50/20	Indirect
Total Net Lumens	412,000					30/30/20	Diffuse
Net Lumens #1	20,600	Gross lumens #1	22,889				Directional
Net Lumens #2	309,000	Gross lumens #2	412,000				
Net Lumens #3	82,400	Gross lumens #3	164,800				
Lamp Lumens #1	28,611	Lamp watts #1	1,431				
Lamp Lumens #2	515,000	Lamp watts #2	5,722				
Lamp Lumens #3	206,000	Lamp watts #3	2,289				

Minimum Theoretical Watts	9,442	
Minimum Theoretical Power Density	1.18	
Recommended Value for Standard	1.20	With Chandelier Allowance

Table A-4 – Church

Space Type	Church		1998 Area LPD	2.1	
Length	60		1998 Bldg LPD	1.8	
Width	50		Ratio	1.2	
Height	20		2003 Area LPD	1.9	
Same as 1998	Yes		2003 Bldg LPD	1.6	
Finishes	70/50/20	3 Light Loss Factor	0.80		
Light Level	Footcandles	% of space			
Task	35	75			
Ambient	15	20			
Other	100	5	Sanctuary		
Lighting Systems	#1	#2	#3		
Lamp	Halogen IR	T8/T5	Halogen IR		
Luminaire	Direct	Indirect	Directional		
Source Code	3	6	3		
RCR	3.21				
Percent of Total	50	40	10	100	
CU of Fixture	0.90	0.40	0.90		
Note/Source	Downlight PAR	Cove light	Track/accent		

Calculations

Average FC	34		
Total Net Lumens	102,750		
Net Lumens #1	51,375	Gross lumens #1	57,083
Net Lumens #2	41,100	Gross lumens #2	102,750
Net Lumens #3	10,275	Gross lumens #3	11,417
Lamp Lumens #1	71,354	Lamp watts #1	3,568
Lamp Lumens #2	128,438	Lamp watts #2	1,427
Lamp Lumens #3	14,271	Lamp watts #3	714

Minimum Theoretical Watts	5,708	
Minimum Theoretical Power Density	1.90	
Recommended Value for Standard	1.90	With Chandelier Allowance

Data Used in Calculations

	Lamp Types	**MLPW**
1	Incandescent	10
2	Halogen	15
3	Halogen IR	20
4	Compact Fluorescent	55
5	Biax/T5HO	75
6	T8/T5	90
7	Ceramic Metal Halide	50
8	Pulse start metal halide	75
9	Other	70

Finishes	**Fixture Types**
80/70/20	Direct
80/50/20	Semi-direct
70/50/20	Direct-indirect
70/30/20	Semi-indirect
50/50/20	Indirect
30/30/20	Diffuse
	Directional

Table A-5 – Classroom

Space Type	Classroom					**Data Used in Calculations**	
Length	30						
Width	30						
Height	10						
Same as 1998	Yes					**Lamp Types**	**MLPW**
Finishes	70/50/20	3 Light Loss Factor	0.80		1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	50	80			4	Compact Fluorescent	55
Ambient	75	20			5	Biax/T5HO	75
Other					6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	T8/T5	Biax/T5HO	Other		9	Other	70
Luminaire	Indirect	Directional	Directional				
Source Code	6	5	9				
RCR	2.50						
Percent of Total	90	10	0	100		**Finishes**	**Fixture Types**
CU of Fixture	0.75	0.40	1.00			80/70/20	Direct
Note/Source	Uplight Finelite	Chalkboard lt				80/50/20	Semi-direct
						70/50/20	Direct-indirect
Calculations						70/30/20	Semi-indirect
Average FC	55					50/50/20	Indirect
Total Net Lumens	49,500					30/30/20	Diffuse
Net Lumens #1	44,550	Gross lumens #1	59,400				Directional
Net Lumens #2	4,950	Gross lumens #2	12,375				
Net Lumens #3	0	Gross lumens #3	0				
Lamp Lumens #1	74,250	Lamp watts #1	825				
Lamp Lumens #2	15,469	Lamp watts #2	206				
Lamp Lumens #3	0	Lamp watts #3	0				

Minimum Theoretical Watts	1,031
Minimum Theoretical Power Density	1.15
Recommended Value for Standard	1.20

Table A-6 – Clinic

Space Type	Clinic		1998 Area LPD	1.4		**Data Used in Calculations**	
Length	40		1998 Bldg LPD	1.2			
Width	40		Ratio	1.2			
Height	10		2003 Area LPD	1.2			
Same as 1998	Yes		2003 Bldg LPD	1.0		**Lamp Types**	**MLPW**
Finishes	70/50/20	3 Light Loss Factor	0.80		1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	75	50			4	Compact Fluorescent	55
Ambient	30	45			5	Biax/T5HO	75
Other	100	5			6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	T8/T5	T8/T5	Biax/T5HO		9	Other	70
Luminaire	Direct	Indirect	Directional				
Source Code	6	6	5				
RCR	1.88						
Percent of Total	55	40	5	100		**Finishes**	**Fixture Types**
CU of Fixture	0.72	0.68	0.50			80/70/20	Direct
Note/Source	Troffer	Uplight	Task light			80/50/20	Semi-direct
						70/50/20	Direct-indirect
Calculations						70/30/20	Semi-indirect
Average FC	56					50/50/20	Indirect
Total Net Lumens	89,600					30/30/20	Diffuse
Net Lumens #1	49,280	Gross lumens #1	68,444				Directional
Net Lumens #2	35,840	Gross lumens #2	52,706				
Net Lumens #3	4,480	Gross lumens #3	8,960				
Lamp Lumens #1	85,556	Lamp watts #1	951				
Lamp Lumens #2	65,882	Lamp watts #2	732				
Lamp Lumens #3	11,200	Lamp watts #3	149				

Minimum Theoretical Watts	1,832
Minimum Theoretical Power Density	1.14
Recommended Value for Standard	1.20

Table A-7 – Convention Center

Space Type	Convention Center		1998 Area LPD	1.5		**Data Used in Calculations**	
Length	100		1998 Bldg LPD	1.4			
Width	80		Ratio	1.1			
Height	15		2003 Area LPD	1.4			
Same as 1998	Yes		2003 Bldg LPD	1.3		**Lamp Types**	**MLPW**
Finishes	70/50/20	3 Light Loss Factor	0.80		1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	50	75			4	Compact Fluorescent	55
Ambient	20	20			5	Biax/T5HO	75
Other	100	5	Accents		6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	Biax/T5HO	T8/T5	Halogen IR		9	Other	70
Luminaire	Direct	Direct-indirect	Direct				
Source Code	5	6	3				
RCR	1.41						
Percent of Total	70	15	15	100		**Finishes**	**Fixture Types**
CU of Fixture	0.75	0.60	0.90			80/70/20	Direct
Note/Source	Troffer	Uplight	Task light			80/50/20	Semi-direct
						70/50/20	Direct-indirect
Calculations						70/30/20	Semi-indirect
Average FC	47					50/50/20	Indirect
Total Net Lumens	372,000					30/30/20	Diffuse
Net Lumens #1	260,400	Gross lumens #1	347,200				Directional
Net Lumens #2	55,800	Gross lumens #2	93,000				
Net Lumens #3	55,800	Gross lumens #3	62,000				
Lamp Lumens #1	434,000	Lamp watts #1	5,787				
Lamp Lumens #2	116,250	Lamp watts #2	1,292				
Lamp Lumens #3	77,500	Lamp watts #3	3,875				

Minimum Theoretical Watts	10,953	
Minimum Theoretical Power Density	1.37	
Recommended Value for Standard	1.40	Plus Chandelier allowance

Table A-8 – Exhibition Hall

Space Type	Exhibition Hall					**Data Used in Calculations**	
Length	200						
Width	200						
Height	30						
Same as 1998	No	Exhibition Halls are large spaces				**Lamp Types**	**MLPW**
Finishes	50/50/20 5	Light Loss Factor	0.80		1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	70	80			4	Compact Fluorescent	55
Ambient	20	20			5	Biax/T5HO	75
Other					6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	Biax/T5HO	Compact Fluorescent	Halogen IR		9	Other	70
Luminaire	Direct	Direct	Direct				
Source Code	5	4	3				
RCR	1.38						
Percent of Total	80	10	10	100		**Finishes**	**Fixture Types**
CU of Fixture	0.70	0.60	0.90			80/70/20	Direct
Note/Source	High Bay	Downlight	House downlight			80/50/20	Semi-direct
						70/50/20	Direct-indirect
						70/30/20	Semi-indirect
						50/50/20	Indirect
						30/30/20	Diffuse
							Directional

Calculations

Average FC	60		
Total Net Lumens	2,400,000		
Net Lumens #1	1,920,000	Gross lumens #1	2,742,857
Net Lumens #2	240,000	Gross lumens #2	400,000
Net Lumens #3	240,000	Gross lumens #3	266,667
Lamp Lumens #1	3,428,571	Lamp watts #1	45,714
Lamp Lumens #2	500,000	Lamp watts #2	9,091
Lamp Lumens #3	333,333	Lamp watts #3	16,667

Minimum Theoretical Watts	71,472
Minimum Theoretical Power Density	1.79
Recommended Value for Standard	1.80

Table A-9 – Kitchen

Space Type	Kitchen					**Data Used in Calculations**	
Length	30						
Width	40						
Height	16						
Same as 1998	Yes					**Lamp Types**	**MLPW**
Finishes	50/50/20	5 Light Loss Factor	0.80		1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	75	50			4	Compact Fluorescent	55
Ambient	30	50			5	Biax/T5HO	75
Other					6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	T8/T5	T8/T5	Compact Florescent			Other	70
Luminaire	Direct	Direct	Direct				
Source Code	6	6	4				
RCR	3.94						
Percent of Total	80	10	10	100		**Finishes**	**Fixture Types**
CU of Fixture	0.55	0.45	0.40			80/70/20	Direct
Note/Source	Troffer	Troffer	Vaportight			80/50/20	Semi-direct
						70/50/20	Direct-indirect
						70/30/20	Semi-indirect
						50/50/20	Indirect
						30/30/20	Diffuse
							Directional

Calculations

Average FC	53		
Total Net Lumens	63,000		
Net Lumens #1	50,400	Gross lumens #1	91,636
Net Lumens #2	6,300	Gross lumens #2	14,000
Net Lumens #3	6,300	Gross lumens #3	15,750
Lamp Lumens #1	114,545	Lamp watts #1	1,273
Lamp Lumens #2	17,500	Lamp watts #2	194
Lamp Lumens #3	19,688	Lamp watts #3	358

Minimum Theoretical Watts	1,825
Minimum Theoretical Power Density	1.52
Recommended Value for Standard	1.60

Table A-10 – Retail

Space Type	Retail		1998 Area LPD	2.0
Length	96		1998 Bldg LPD	1.7
Width	94		Ratio	1.2
Height	19		2003 Area LPD	1.8
Same as 1998	Yes		2003 Bldg LPD	1.5
Finishes	50/50/20	5 Light Loss Factor	0.80	

Light Level	Footcandles	% of space
Task	70	70
Ambient	30	20
Other	100	10

Lighting Systems	#1	#2	#3	
Lamp	T8/T5	T8/T5	Halogen IR	
Luminaire	Direct	Directional	Directional	
Source Code	6	6	3	
RCR	1.74			
Percent of Total	75	10	15	100
CU of Fixture	0.80	0.40	0.90	
Note/Source	General lighting	Valance	Accents	

Calculations

Average FC	65		
Total Net Lumens	586,560		
Net Lumens #1	439,920	Gross lumens #1	549,900
Net Lumens #2	58,656	Gross lumens #2	146,640
Net Lumens #3	87,984	Gross lumens #3	97,760
Lamp Lumens #1	687,375	Lamp watts #1	7,638
Lamp Lumens #2	183,300	Lamp watts #2	2,037
Lamp Lumens #3	122,200	Lamp watts #3	6,110

Minimum Theoretical Watts	15,784
Minimum Theoretical Power Density	1.75
Recommended Value for Standard	1.80

Data Used in Calculations

	Lamp Types	**MLPW**
1	Incandescent	10
2	Halogen	15
3	Halogen IR	20
4	Compact Fluorescent	55
5	Biax/T5HO	75
6	T8/T5	90
7	Ceramic Metal Halide	50
8	Pulse start metal halide	75
9	Other	70

Finishes	**Fixture Types**
80/70/20	Direct
80/50/20	Semi-direct
70/50/20	Direct-indirect
70/30/20	Semi-indirect
50/50/20	Indirect
30/30/20	Diffuse
	Directional

Table A-11 – Hotel

Space Type	Hotel	**Complete Building**				**Data Used in Calculations**	
Length	60						
Width	50						
Height	13						
Same as 1998	Yes					**Lamp Types**	**MLPW**
Finishes	50/50/20 5	Light Loss Factor	0.80		1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	50	30	Desk		4	Compact Fluorescent	55
Ambient	30	50	General ambient		5	Biax/T5HO	75
Other	70	20	Displays		6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	Ceramic Metal Halide	T8/T5	Halogen IR		9	Other	70
Luminaire	Direct	Indirect	Direct				
Source Code	7	6	3				
RCR	1.93						
Percent of Total	50	25	25	100		**Finishes**	**Fixture Types**
CU of Fixture	0.65	0.40	0.90			80/70/20	Direct
Note/Source	Lithonia AH6	Cove	Lithonia RP6			80/50/20	Semi-direct
						70/50/20	Direct-indirect
Calculations						70/30/20	Semi-indirect
Average FC	44					50/50/20	Indirect
Total Net Lumens	132,000					30/30/20	Diffuse
Net Lumens #1	66,000	Gross lumens #1	101,538				Directional
Net Lumens #2	33,000	Gross lumens #2	82,500				
Net Lumens #3	33,000	Gross lumens #3	36,667				
Lamp Lumens #1	126,923	Lamp watts #1	2,538				
Lamp Lumens #2	103,125	Lamp watts #2	1,146				
Lamp Lumens #3	45,833	Lamp watts #3	2,292				

Minimum Theoretical Watts	5,976	
Minimum Theoretical Power Density	1.99	
Recommended Value for Standard	2.00	Plus chandelier allowance

Table A-12 – Office

Space Type	Office		1998 Area LPD	1.3		**Data Used in Calculations**	
Length	60		1998 Bldg LPD	1.2			
Width	40		Ratio	1.1			
Height	9		2003 Area LPD	1.2			
Same as 1998	Yes		2003 Bldg LPD	1.1		**Lamp Types**	**MLPW**
Finishes	80/50/20	2 Light Loss Factor	0.80		1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	75	50	Tasks		4	Compact Fluorescent	55
Ambient	30	50	General ambient		5	Biax/T5HO	75
Other					6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	T8/T5	T8/T5	Compact fluorescent		9	Other	70
Luminaire	Indirect	Direct	Directional				
Source Code	6	6	4				
RCR	1.35						
Percent of Total	65	25	10	100		**Finishes**	**Fixture Types**
CU of Fixture	0.78	0.50	0.63			80/70/20	Direct
Note/Source	Generic uplight	Task light	Lithonia AFV6			80/50/20	Semi-direct
						70/50/20	Direct-indirect
						70/30/20	Semi-indirect
						50/50/20	Indirect
						30/30/20	Diffuse
							Directional

Calculations

Average FC	53		
Total Net Lumens	126,000		
Net Lumens #1	81,900	Gross lumens #1	105,000
Net Lumens #2	31,500	Gross lumens #2	63,000
Net Lumens #3	12,600	Gross lumens #3	20,000
Lamp Lumens #1	131,250	Lamp watts #1	1,458
Lamp Lumens #2	78,750	Lamp watts #2	875
Lamp Lumens #3	25,000	Lamp watts #3	455

Minimum Theoretical Watts	2,788	
Minimum Theoretical Power Density	1.16	
Recommended Value for Standard	1.20	Allow 0.2 for task only

Table A-13 – Laundry

Space Type	Laundry					**Data Used in Calculations**	
Length	60						
Width	50						
Height	10						
Same as 1998	Yes					**Lamp Types**	**MLPW**
Finishes	80/50/20	2 Light Loss Factor	0.80		1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	75	45	Desk		4	Compact Fluorescent	55
Ambient	30	50	General ambient		5	Biax/T5HO	75
Other					6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	T8/T5	T8/T5	Compact Fluorescent		9	Other	70
Luminaire	Indirect	Direct	Directional				
Source Code	6	6	4				
RCR	1.38						
Percent of Total	100	0	0	100		**Finishes**	**Fixture Types**
CU of Fixture	0.75	1.00	1.00			80/70/20	Direct
Note/Source	Troffer	Task light	Lithonia AFV6			80/50/20	Semi-direct
						70/50/20	Direct-indirect
Calculations						70/30/20	Semi-indirect
Average FC	49					50/50/20	Indirect
Total Net Lumens	146,250					30/30/20	Diffuse
Net Lumens #1	146,250	Gross lumens #1	195,000				Directional
Net Lumens #2	0	Gross lumens #2	0				
Net Lumens #3	0	Gross lumens #3	0				
Lamp Lumens #1	243,750	Lamp watts #1	2,708				
Lamp Lumens #2	0	Lamp watts #2	0				
Lamp Lumens #3	0	Lamp watts #3	0				

Minimum Theoretical Watts	2,708
Minimum Theoretical Power Density	0.90
Recommended Value for Standard	0.90

Table A-14 – Industrial High Bay

Space Type	Industrial High Bay	1998 Area LPD	1.2			**Data Used in Calculations**	
Length	100	1998 Bldg LPD	1.2				
Width	100	Ratio	1.0				
Height	35	2003 Area LPD	1.1				
Same as 1998	No	2003 Bldg LPD	1.1			**Lamp Types**	**MLPW**
Finishes	30/30/20 6	Light Loss Factor	0.80		1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	50	50	Work stations		4	Compact Fluorescent	55
Ambient	30	50	General ambient		5	Biax/T5HO	75
Other					6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	P-S Metal Halide	T8/T5	Compact Fluorescent		9	Other	70
Luminaire	Direct	Direct	Directional				
Source Code	8	6	4				
RCR	3.25						
Percent of Total	80	20	0	100		**Finishes**	**Fixture Types**
CU of Fixture	0.57	0.75	1.00			80/70/20	Direct
Note/Source	Lithonia THP	Lithonia EJ	Lithonia AFV6			80/50/20	Semi-direct
						70/50/20	Direct-indirect
Calculations						70/30/20	Semi-indirect
						50/50/20	Indirect
						30/30/20	Diffuse
							Directional

Average FC	40		
Total Net Lumens	400,000		
Net Lumens #1	320,000	Gross lumens #1	561,404
Net Lumens #2	80,000	Gross lumens #2	106,667
Net Lumens #3	0	Gross lumens #3	0
Lamp Lumens #1	701,754	Lamp watts #1	9,357
Lamp Lumens #2	133,333	Lamp watts #2	1,481
Lamp Lumens #3	0	Lamp watts #3	0

Minimum Theoretical Watts	10,838
Minimum Theoretical Power Density	1.08
Recommended Value for Standard	1.10

Table A-15 – Industrial Precision

Space Type	Industrial Precision					**Data Used in Calculations**	
Length	100						
Width	100						
Height	20						
Same as 1998	No	Not modeled in 98				**Lamp Types**	**MLPW**
Finishes	50/50/20	5 Light Loss Factor	0.80		1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	100	50	Work stations		4	Compact Fluorescent	55
Ambient	30	50	General ambient		5	Biax/T5HO	75
Other					6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	T8/T5	T8/T5	Compact Fluorescent		9	Other	70
Luminaire	Direct	Direct	Directional				
Source Code	6	6	4				
RCR	1.75						
Percent of Total	60	40	0	100		**Finishes**	**Fixture Types**
CU of Fixture	0.70	0.75	1.00			80/70/20	Direct
Note/Source	Lithonia PV	Lithonia EJ	Lithonia AFV6			80/50/20	Semi-direct
						70/50/20	Direct-indirect
Calculations						70/30/20	Semi-indirect
Average FC	65					50/50/20	Indirect
Total Net Lumens	650,000					30/30/20	Diffuse
Net Lumens #1	390,000	Gross lumens #1	557,143				Directional
Net Lumens #2	260,000	Gross lumens #2	346,667				
Net Lumens #3	0	Gross lumens #3	0				
Lamp Lumens #1	696,429	Lamp watts #1	7,738				
Lamp Lumens #2	433,333	Lamp watts #2	4,815				
Lamp Lumens #3	0	Lamp watts #3	0				

Minimum Theoretical Watts	12,553
Minimum Theoretical Power Density	1.26
Recommended Value for Standard	1.30

Table A-16 – Airport Holdroom

Space Type	Airport Holdroom					**Data Used in Calculations**	
Length	100						
Width	60						
Height	12						
Same as 1998	N/A					**Lamp Types**	**MLPW**
Finishes	70/50/20	3	Light Loss Factor	0.80	1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	70	10	Lift counter		4	Compact Fluorescent	55
Ambient	30	80	general		5	Biax/T5HO	75
Other	100	10	Displays		6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	T8/T5	T8/T5	T8/T5		9	Other	70
Luminaire	Semi-direct	Direct	Directional				
Source Code	6	6	6				
RCR	1.27						
Percent of Total	60	30	10	100		**Finishes**	**Fixture Types**
CU of Fixture	0.60	0.55	0.25			80/70/20	Direct
Note/Source	Pendants	Task lights	Wallwash			80/50/20	Semi-direct
						70/50/20	Direct-indirect
						70/30/20	Semi-indirect
						50/50/20	Indirect
						30/30/20	Diffuse
							Directional

Calculations

Average FC	41		
Total Net Lumens	246,000		
Net Lumens #1	147,600	Gross lumens #1	246,000
Net Lumens #2	73,800	Gross lumens #2	134,182
Net Lumens #3	24,600	Gross lumens #3	98,400
Lamp Lumens #1	307,500	Lamp watts #1	3,417
Lamp Lumens #2	167,727	Lamp watts #2	1,864
Lamp Lumens #3	123,000	Lamp watts #3	1,367

Minimum Theoretical Watts	6,647	
Minimum Theoretical Power Density	1.11	
Recommended Value for Standard	1.20	With chandelier allowance

Table A-17 – Air Ticket Counter

Space Type	Air ticket counter				
Length	200				
Width	60				
Height	16				
Same as 1998	N/A				
Finishes	70/50/20	3	Light Loss Factor	0.80	
Light Level	Footcandles	% of space			
Task	70	20	Specific tasks		
Ambient	50	40	general		
Other	20	40	Ambient		
Lighting Systems	#1	#2	#3		
Lamp	T8/T5	T8/T5	T8/T5		
Luminaire	Indirect	Direct	Directional		
Source Code	6	6	6		
RCR	1.46				
Percent of Total	40	40	20	100	
CU of Fixture	0.48	0.60	0.40		
Note/Source	Uplight coves	Pendant task	Wallwash		

Data Used in Calculations

	Lamp Types	**MLPW**
1	Incandescent	10
2	Halogen	15
3	Halogen IR	20
4	Compact Fluorescent	55
5	Biax/T5HO	75
6	T8/T5	90
7	Ceramic Metal Halide	50
8	Pulse start metal halide	75
9	Other	70

Finishes	**Fixture Types**
80/70/20	Direct
80/50/20	Semi-direct
70/50/20	Direct-indirect
70/30/20	Semi-indirect
50/50/20	Indirect
30/30/20	Diffuse
	Directional

Calculations

Average FC	42		
Total Net Lumens	504,000		
Net Lumens #1	201,600	Gross lumens #1	420,000
Net Lumens #2	201,600	Gross lumens #2	336,000
Net Lumens #3	100,800	Gross lumens #3	252,000
Lamp Lumens #1	525,000	Lamp watts #1	5,833
Lamp Lumens #2	420,000	Lamp watts #2	4,667
Lamp Lumens #3	315,000	Lamp watts #3	3,500

Minimum Theoretical Watts	14,000	
Minimum Theoretical Power Density	1.17	
Recommended Value for Standard	1.20	Recommend chandelier allowance

Table A-18 – Mail Sorting

Space Type	Mail sorting				
Length	100				
Width	60				
Height	16				
Same as 1998	N/A				
Finishes	70/50/20	3	Light Loss Factor	0.80	
Light Level	Footcandles	% of space			
Task	100	20	Specific tasks		
Ambient	70	40	General work		
Other	30	40	Ambient		
Lighting Systems	#1	#2	#3		
Lamp	T8/T5	T8/T5	T8/T5		
Luminaire	Direct-indirect	Direct	Directional		
Source Code	6	6	6		
RCR	1.80				
Percent of Total	80	10	10	100	
CU of Fixture	0.60	0.40	0.40		
Note/Source	Pendant	Task	Wallwash		

Data Used in Calculations

	Lamp Types	**MLPW**
1	Incandescent	10
2	Halogen	15
3	Halogen IR	20
4	Compact Fluorescent	55
5	Biax/T5HO	75
6	T8/T5	90
7	Ceramic Metal Halide	50
8	Pulse start metal halide	75
9	Other	70

Finishes	**Fixture Types**
80/70/20	Direct
80/50/20	Semi-direct
70/50/20	Direct-indirect
70/30/20	Semi-indirect
50/50/20	Indirect
30/30/20	Diffuse
	Directional

Calculations

Average FC	60		
Total Net Lumens	360,000		
Net Lumens #1	288,000	Gross lumens #1	480,000
Net Lumens #2	36,000	Gross lumens #2	90,000
Net Lumens #3	36,000	Gross lumens #3	90,000
Lamp Lumens #1	600,000	Lamp watts #1	6,667
Lamp Lumens #2	112,500	Lamp watts #2	1,250
Lamp Lumens #3	112,500	Lamp watts #3	1,250

Minimum Theoretical Watts	9,167
Minimum Theoretical Power Density	1.53
Recommended Value for Standard	1.60

Table A-19 – Police Hearing/Waiting

Space Type	Police Hearing/waiting					**Data Used in Calculations**	
Length	40						
Width	20						
Height	12						
Same as 1998	N/A					**Lamp Types**	**MLPW**
Finishes	70/50/20	3 Light Loss Factor	0.80		1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	50	50	General		4	Compact Fluorescent	55
Ambient	30	40			5	Biax/T5HO	75
Other	70	10	Walls, tasks		6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	T8/T5	T8/T5	Compact fluorescent		9	Other	70
Luminaire	Direct-indirect	Directional	Direct				
Source Code	6	6	4				
RCR	3.56						
Percent of Total	80	10	10	100		**Finishes**	**Fixture Types**
CU of Fixture	0.60	0.30	0.40			80/70/20	Direct
Note/Source	Pendant	Wallwash	Task			80/50/20	Semi-direct
						70/50/20	Direct-indirect
						70/30/20	Semi-indirect
						50/50/20	Indirect
						30/30/20	Diffuse
							Directional

Calculations

Average FC	44		
Total Net Lumens	35,200		
Net Lumens #1	28,160	Gross lumens #1	46,933
Net Lumens #2	3,520	Gross lumens #2	11,733
Net Lumens #3	3,520	Gross lumens #3	8,800
Lamp Lumens #1	58,667	Lamp watts #1	652
Lamp Lumens #2	14,667	Lamp watts #2	163
Lamp Lumens #3	11,000	Lamp watts #3	200

Minimum Theoretical Watts	1,015
Minimum Theoretical Power Density	1.27
Recommended Value for Standard	1.30

Table A-20 – Jail

Space Type	Jail				
Length	20				
Width	20				
Height	12				
Same as 1998	N/A				
Finishes	70/50/20	3	Light Loss Factor	0.80	
Light Level	Footcandles	% of space			
Task	20	100			
Ambient					
Other					
Lighting Systems	#1	#2	#3		
Lamp	T8/T5	Other	Other		
Luminaire	Direct	Diffuse	Directional		
Source Code	6	9	9		
RCR	4.75				
Percent of Total	100			100	
CU of Fixture	0.30	0.10	0.10		
Note/Source	High abuse				

Data Used in Calculations

	Lamp Types	MLPW
1	Incandescent	10
2	Halogen	15
3	Halogen IR	20
4	Compact Fluorescent	55
5	Biax/T5HO	75
6	T8/T5	90
7	Ceramic Metal Halide	50
8	Pulse start metal halide	75
9	Other	70

Finishes	Fixture Types
80/70/20	Direct
80/50/20	Semi-direct
70/50/20	Direct-indirect
70/30/20	Semi-indirect
50/50/20	Indirect
30/30/20	Diffuse
	Directional

Calculations

Average FC	20		
Total Net Lumens	8,000		
Net Lumens #1	8,000	Gross lumens #1	26,667
Net Lumens #2	0	Gross lumens #2	0
Net Lumens #3	0	Gross lumens #3	0
Lamp Lumens #1	33,333	Lamp watts #1	370
Lamp Lumens #2	0	Lamp watts #2	0
Lamp Lumens #3	0	Lamp watts #3	0

Minimum Theoretical Watts	370
Minimum Theoretical Power Density	0.93
Recommended Value for Standard	1.00

Table A-21 – Senior Reading Sitting

Space Type	Senior Reading Sitting					**Data Used in Calculations**	
Length	60						
Width	30						
Height	10						
Same as 1998	N/A					**Lamp Types**	**MLPW**
Finishes	70/50/20	3	Light Loss Factor	0.80	1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	50	50	RP-28 values		4	Compact Fluorescent	55
Ambient	30	45			5	Biax/T5HO	75
Other	50	5	Accent		6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	T8/T5	Compact fluorescent	Halogen IR		9	Other	70
Luminaire	Direct	Diffuse	Directional				
Source Code	6	4	3				
RCR	1.88						
Percent of Total	80	15	5	100		**Finishes**	**Fixture Types**
CU of Fixture	0.55	0.30	0.75			80/70/20	Direct
Note/Source	Indirect cove	Decorative	Accent light			80/50/20	Semi-direct
						70/50/20	Direct-indirect
						70/30/20	Semi-indirect
						50/50/20	Indirect
						30/30/20	Diffuse
							Directional

Calculations

Average FC	41		
Total Net Lumens	73,800		
Net Lumens #1	59,040	Gross lumens #1	107,345
Net Lumens #2	11,070	Gross lumens #2	36,900
Net Lumens #3	3,690	Gross lumens #3	4,920
Lamp Lumens #1	134,182	Lamp watts #1	1,491
Lamp Lumens #2	46,125	Lamp watts #2	839
Lamp Lumens #3	6,150	Lamp watts #3	308

Minimum Theoretical Watts	2,637	
Minimum Theoretical Power Density	1.47	
Recommended Value for Standard	1.50	Consider chandelier allowance?

Table A-22 – Housing Commons

Space Type	Housing Commons					**Data Used in Calculations**	
Length	36						
Width	16						
Height	10						
Same as 1998	N/A					**Lamp Types**	**MLPW**
Finishes	70/50/20	3 Light Loss Factor	0.80		1	Incandescent	10
					2	Halogen	15
Light Level	Footcandles	% of space			3	Halogen IR	20
Task	30	50			4	Compact Fluorescent	55
Ambient	20	45			5	Biax/T5HO	75
Other	50	5	Accent		6	T8/T5	90
					7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3		8	Pulse start metal halide	75
Lamp	T8/T5	Compact fluorescent	Halogen IR		9	Other	70
Luminaire	Direct	Diffuse	Directional				
Source Code	6	4	3				
RCR	3.39						
Percent of Total	80	15	5	100		**Finishes**	**Fixture Types**
CU of Fixture	0.55	0.30	0.75			80/70/20	Direct
Note/Source	Troffers	Sconces	Accent light			80/50/20	Semi-direct
						70/50/20	Direct-indirect
						70/30/20	Semi-indirect
						50/50/20	Indirect
						30/30/20	Diffuse
							Directional

Calculations

Average FC	27		
Total Net Lumens	15,264		
Net Lumens #1	12,211	Gross lumens #1	22,202
Net Lumens #2	2,290	Gross lumens #2	7,632
Net Lumens #3	763	Gross lumens #3	1,018
Lamp Lumens #1	27,753	Lamp watts #1	308
Lamp Lumens #2	9,540	Lamp watts #2	173
Lamp Lumens #3	1,272	Lamp watts #3	64

Minimum Theoretical Watts	545
Minimum Theoretical Power Density	0.95
Recommended Value for Standard	1.00

Table A-23 – Civic Waiting Room

Space Type	Civic Waiting room				**Data Used in Calculations**	
Length	40					
Width	20					
Height	10					
Same as 1998	N/A				**Lamp Types**	**MLPW**
Finishes	70/50/20 3	Light Loss Factor	0.80	1	Incandescent	10
				2	Halogen	15
Light Level	Footcandles	% of space		3	Halogen IR	20
Task	50	50		4	Compact Fluorescent	55
Ambient	30	45		5	Biax/T5HO	75
Other	100	5	Artwork, display	6	T8/T5	90
				7	Ceramic Metal Halide	50
Lighting Systems	#1	#2	#3	8	Pulse start metal halide	75
Lamp	T8/T5	Compact fluorescent	Halogen IR	9	Other	70
Luminaire	Semi-indirect	Directional	Directional			
Source Code	6	4	3			
RCR	2.81					
Percent of Total	80	15	5	100	**Finishes**	**Fixture Types**
CU of Fixture	0.70	0.30	1.00		80/70/20	Direct
Note/Source	Uplight	Wallwasher	Accent light		80/50/20	Semi-direct
					70/50/20	Direct-indirect
Calculations					70/30/20	Semi-indirect
Average FC	44				50/50/20	Indirect
Total Net Lumens	34,800				30/30/20	Diffuse
Net Lumens #1	27,840	Gross lumens #1	39,771			Directional
Net Lumens #2	5,220	Gross lumens #2	17,400			
Net Lumens #3	1,740	Gross lumens #3	1,740			
Lamp Lumens #1	49,714	Lamp watts #1	552			
Lamp Lumens #2	21,750	Lamp watts #2	395			
Lamp Lumens #3	2,175	Lamp watts #3	109			

Minimum Theoretical Watts	1,057	
Minimum Theoretical Power Density	1.32	
Recommended Value for Standard	1.40	With chandelier allowance in addition.

Appendix B – Rationale For Removing the 800 ppm CO_2 Requirement In California Title 24

Issue

California Title 24, § 121(c) requires that if carbon dioxide (CO_2) based demand controlled ventilation (DCV) is used, CO_2 concentration must not exceed 800 parts per million (ppm).

Findings

There is no public health justification for sustaining the requirement of CO_2 concentrations of 800 ppm in Title 24, § 121(c). Scientific literature supports that ventilation rates reflected in CO_2 concentrations in the range of 1,000 to 1,200 ppm as typically found in buildings provide an environmentally acceptable indoor environment.

By maintaining the 800 ppm recommended level, California buildings utilizing CO_2 DCV will be ventilated at a rate 50% higher than the 15cfm/person ventilation rate required by the code. This will result in significant over-ventilation and unnecessary energy waste in California buildings.

Current industry standard and practice for use of CO_2 for ventilation control supports removal of the 800 ppm requirement in the current Title 24 standard.

Recommendation

Remove reference to the requirement for 800 ppm maximum level of CO_2 in California Title 24.

In place of a fixed indoor CO_2 concentration, the standard should require that ventilation systems utilizing DCV must be designed to maintain ventilation rates at 15 cfm/person based on actual occupancy. This rate can be equated to a differential CO_2 concentration between inside and outside concentrations as a function of the activity level. For normal office activity levels, 15 cfm/person equates to 700 ppm CO_2 between inside and outside concentrations. The nonresidential manual should provide instructions for calculating the appropriate differential concentration and for estimating an acceptable outdoor air concentration for systems where only inside concentration is measured.

Background

Source of the 800 ppm Level in the Current Title 24

The 800 ppm level was adopted into the building energy efficiency standards in 1991. The actual source of and rationale for this particular limit is not known.

In 1994, OSHA proposed a rule for indoor air quality in the workplace, that included an operational requirement that space CO_2 levels not exceed 800 ppm.[27] The 800 ppm level is based on maintaining 20 cfm/person, as recommended by ASHRAE Standard 62-1989 for office spaces, at an outside concentration of 300 ppm, also implied by ASHRAE Standard 62 at that time. Assuming a 1.2 MET activity level (typical of offices) and 20 cfm/person, the inside-to-outside CO_2 concentration differential is approximately 530 ppm, resulting in a space concentration of 830 ppm at an outdoor air concentration of 300 ppm. However, actual outside levels are typically between 350 and 450 ppm, with the lowest concentrations currently measured being 360 ppm atop Manua Loa in Hawaii.[28]

---

27 OSHA Proposed Rule On Workplace Indoor Air Quality, 1994

28 C.D. Keeling, T.P. Whorf, Scripps Institution Of Oceanography, University of California, La Jolla, CA.

OSHA received many comments on the proposed ruling. OSHA never adopted the proposed rule and finally withdrew it late last year.

Using CO_2 Concentration To Control Ventilation

People are the primary source of CO_2 in indoor spaces. People exhale CO_2 concentrations at a predictable rate according to their level of metabolic activity.[29] Outdoor concentrations of CO_2 are typically very low in the 350 to 450 ppm range.[30] An indoor measurement of CO_2 is therefore a dynamic measure of the number of people in a space exhaling CO_2 and the amount of ventilated outside air being introduced to the space for dilution. Using well-established principals, it is possible to correlate CO_2 concentrations to specific ventilation rates per person. This relationship is explained in great detail by Emmeric and Persily in their recent report to the California Energy Commission. These principals correlating CO_2 levels to cfm/person ventilation rates are also recognized by ASHRAE Standard 62[31], ASHRAE Standard 90.1[32], and the 2000 International Mechanical Code[33].

Using these principals, the 800 ppm level required in Title 24 translates into a ventilation rate of about 23 cfm/person. A ventilation rate of 15 cfm/person as required by Title 24 results in a maximum CO_2 concentration of 1100 ppm assuming typical outdoor concentrations of 400 ppm. Confirmation of this principal can be found in Appendix D to ASHRAE standard 62 where a maximum inside/outside CO_2 differential level of 700 ppm is recommended to provide a ventilation rate of 15 cfm/person (700 ppm + 400 ppm outside = 1100).[34]

The graph below shows the correlation between CO_2 levels and ventilation rates using the above referenced principals assuming an office type activity level and outside concentration of 400 ppm.

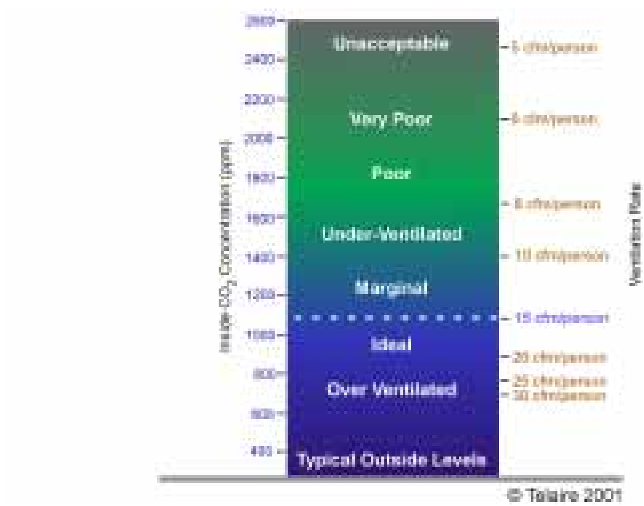

Figure B-1 – Correlation Between CO_2 Levels and Ventilation Rates

Control systems can use in-space CO_2 concentrations to maintain a target cfm/person ventilation rate by considering the rate of CO_2 buildup in the space. In providing ventilation control, the consideration of an

29 ASHRAE, ASHRAE/ANSI Standard 62-2001, Ventilation For Acceptable Indoor Air Quality, Appendix D, 2001.

30 Schell, M.B., S.C. Turner, and R.O. Shim. 1998. Application of CO2-Based Demand-Controlled Ventilation Using ASHRAE Standard 62: Optimizing Energy Use and Ventilation. ASHRAE Transactions 104: 1213-1225.

31 ASHRAE, ASHRAE/ANSI Standard 62-2001, Ventilation For Acceptable Indoor Air Quality.

32 ASHRAE, Users Manual for ASHRAE/ANSI Standard 90.1, 1999.

33 International Code Council, Commentary To The International Mechanical Code 2000, Section 403.3.

34 ASHRAE, ASHRAE/ANSI Standard 62-2001, Ventilation For Acceptable Indoor Air Quality, Appendix D, 2001.

absolute value of CO_2 is only part of the overall control strategy. The most important consideration is the cfm/person target ventilation rate.

Normal Concentrations of Carbon Dioxide Are Not a Health Concern

According to Andy Persily, Chairman of the ASHRAE 62 Committee on Ventilation For Acceptable Indoor Air Quality, in a recent document prepared for the California Energy Commission (PIER division):[35]

> "Carbon dioxide is not generally considered to be a health concern at typical indoor concentrations. The time-weighted average threshold limit value (8 hour exposure and a 40 hour work week) for carbon dioxide is 5,000 ppm, and the short-term exposure limit (15 min) is 30,000 ppm (ACGIH 2001). A number of studies at elevated concentrations, about 5 % carbon dioxide in air or 50,000 ppm, have been performed, and the lowest level at which effects have been seen in humans and animals is about 1 %, i.e., 10,000 ppm (EPA 1991). Indoor carbon dioxide concentrations will not reach these levels unless the ventilation rate is extremely low, about 2 cfm/person for 5,000 ppm and less than about 0.4 cfm/person for 30,000 ppm."

The minimal effect level of 10,000 ppm CO_2 noted above is far above the current CEC 800 ppm threshold, indicating that the 800 ppm concentration is not health related. The same report provides a comprehensive review of the current literature regarding CO_2 and ventilation control, and is an excellent and comprehensive reference on the topic of CO_2 and ventilation.

In addition, other scientific literature supports that ventilation rates reflected in CO_2 concentrations in the range of 1,000 to 1,200 ppm provide an environmentally acceptable indoor environment. [36] [37] No studies exist in the medical or scientific literature that correlates low concentrations of CO_2 (i.e. less than 5000 ppm) as a health risk.

---

35 S.J. Emmerick, A.K. Persily, State of the Art Review Of CO2 Demand Control Technology and Applications, Prepared for the California Energy Commission (PIER division) by the National Institute of Standards. NISTIR 6729. March 2001.

36 M.M Mendell, Non Specific Symptoms In Office Workers: A Review and Summary Of the Epidemiologic Literature, Indoor Air 1993, pp 227-236.

37 O.A. Seppanen, W.J. Fisk, M.J. Mendell, Association Of Ventilation rates and CO2 concentrations with Health And Other Responses In Commercial and Institutional Buildings, Indoor Air 1999, pp 226-252.

Appendix C – Insulation Inspection Checklist

- ☐ Insulation Certificate, signed by responsible party stating:

  Manufacturer's name
  Installed R-values for Walls, Ceiling and Floors
  For Blown-in insulation: minimum weight per square foot

Walls

- ☐ No gaps
- ☐ No compression
- ☐ Insulation cut around obstructions
- ☐ Stapling correct: no gaps, cavity filled
- ☐ External channels, corners, and areas around tubs and showers insulated
- ☐ Small spaces filled
- ☐ Rim-joists insulated

Ceiling Batts

- ☐ No gaps
- ☐ No compression
- ☐ Insulation cut around obstructions
- ☐ All draft stops in place
- ☐ Batts cover trusses
- ☐ All top plates covered
- ☐ All venting clear: minimum 1" clearance
- ☐ IC rated fixtures covered
- ☐ Attic access insulated

Ceiling Blown-in

- ☐ All draft stops in place
- ☐ All drops covered with hard covers
- ☐ Insulation covers entire surface
- ☐ Insulation uniform depth
- ☐ Insulation at proper depth – insulation rulers visible and indicating proper depth

  Note: cellulose insulation settles. Nominal settling for loose fill cellulose is 20% and for stabilized 5%; installers should either over-blow by these percentages or to manufacturer's specifications

- ☐ Insulation covering cavities, drops, scuttles, bracing, and IC rated fixtures
- ☐ Insulation covering top plates
- ☐ Baffles installed and eaves vents or soffit vents clear: minimum 1" clearance
- ☐ Bag labels cut out and stapled to truss vertical near attic access

- ☐ Attic access insulated

Floor

- ☐ Batts snug but not compressed or buckled
- ☐ All spaces insulated
- ☐ If web trusses, rim joists insulated